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THE TECHNOLOGY QUARTERLY

AND

PROCEEDINGS OF THE SOCIETY OF ARTS.

EDITED BY

ROBERT P. BIGELOW, Ph. D.,

Secretary of the Society.

THE TECHNOLOGY QUARTERLY is an illustrated magazine published by the MASSACHUSETTS INSTITUTE OF TECHNOLOGY. It is devoted to original articles upon various subjects in **Architecture, Civil Engineering, Mechanical Engineering, Electrical Engineering, Physics, Chemistry, Biology, Bacteriology, Mining** and **Metallurgy,** or, in general, the **Sciences** and their applications to the **Useful Arts.** Attention is called to two especially notable features of the QUARTERLY, viz.: *The Results of Tests made in the Engineering Laboratories* and *The Review of American Chemical Research.*

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TECHNOLOGY QUARTERLY

AND

PROCEEDINGS OF THE SOCIETY OF ARTS.

VOL. X. MARCH, 1897. NO. 1.

PROCEEDINGS OF THE SOCIETY OF ARTS.

THIRTY-FIFTH YEAR, 1896–97.

THURSDAY, October 8, 1896.

THE 488th regular meeting of the SOCIETY OF ARTS was held this day at the Institute at 8 P.M., the President in the chair.

The record of the previous meeting was read and approved.

Messrs. Louis F. Cutter, of Winchester, R. R. Taylor, of Tuskegee, Alabama, Frank M. James, of Haverhill, Horace J. Howe, of Medford, Charles H. Chase, of Medford, and Frank Vogel, of the Institute, were duly elected Associate Members of the Society.

The following papers were presented by title:

"Hydrolysis of Ferric Chloride," by H. M. Goodwin.

"An Improvement in the Sedgwick-Rafter Method for the Microscopical Examination of Drinking Water," by D. D. Jackson.

"Experience with the Sedgwick-Rafter Method at the Biological Laboratory of the Boston Water Works," by G. C. Whipple.

"Instruction in Theoretical Chemistry," by A. A. Noyes.

"Origin of Pegmatite," by W. O. Crosby and M. L. Fuller.

"Determination of Reducing Sugars in Terms of Cupric Oxide," by George Defren.

"The Viscosity of Mercury Vapor," by H. M. Goodwin and A. A. Noyes.

Before introducing the speakers of the evening, the President made a few remarks calling attention to the recently issued double number of the TECHNOLOGY QUARTERLY and to the excellence of the work of the Institute as reflected in its pages, especial mention being made of the *Results of Tests Made in the Engineering Laboratory* and of the *Review of American Chemical Research.*

Professor William T. Sedgwick then read a paper on "The Milk-Supply Problem." The value of milk as food was first spoken of, and then the process by which a large city is supplied was described in detail. The difficulties in the way of cleanliness and the danger of infection were pointed out. The mixing of milk by the dealers was declared to be the worst feature of the system in Boston, owing to the greatly increased chance for the spread of infection. Pasteurizing was suggested as a partial solution of the problem of pure milk supply of large cities.

Mr. Samuel C. Prescott then read a paper, of which he is joint author with Mr. W. Lyman Underwood, on "An Investigation of the Causes of Spoiling in Certain Kinds of Canned Foods." The authors found eight species of bacteria in spoiled cans of lobster and clams. It was found by experiment that the old method of heating in the water bath was not sufficient to insure sterilization of cans inoculated with these bacteria, but heating in retorts with steam under fifteen pounds pressure, giving a temperature of 250° F., was always successful. Specimens of several of the species were exhibited, together with both good and spoiled cans of clams and lobster.

The President thanked the speakers for their very interesting papers, and the Society adjourned.

THURSDAY, October 22, 1896.

The 489th meeting of the SOCIETY OF ARTS was held at the Institute this day at 8 P.M., Mr. Blodgett in the chair.

The record of the previous meeting was read and approved.

There being no further business, the President introduced Professor E. B. Homer, of the Institute, who read a paper on "A Bicycle Tour Through Surrey, Normandy, and Touraine." The paper was an

account of the excursion made by the Summer School of Architecture of 1896. The students under the direction of Professor Homer, traveled on bicycles through the countries named and made sketches and photographs of the many interesting works of architecture upon their route. The lecture was illustrated by over a hundred views made from photographs taken by members of the party. The paper is published in full in the present number of the TECHNOLOGY QUARTERLY.

The Chair thanked Professor Homer for his very interesting paper, and the Society adjourned.

THURSDAY, November 12, 1896.

The 490th meeting of the SOCIETY OF ARTS was held this day at the Institute, President Walker in the chair.

The record of the previous meeting was read and approved.

Messrs. Louis J. Schiller, of Boston, and J. P. B. Fiske, of Auburndale, were duly elected Associate Members of the Society.

The Society then proceeded to the consideration of the paper of the evening "On the Scientific work of Last Summer's Expedition to Umanak Fiord, West Greenland," by Professor A. E. Burton and Assistant Professor G. H. Barton.

Professor Burton spoke of the general plan of the expedition. He described the apparatus used in making the pendulum and magnetic observations, and the stations in which they were set up, such stations being established at several points on the coasts of Labrador and Greenland.[1] The motion of the ice in the Karajak Glacier was studied. A thermaphone made especially for the expedition by Mr. A. M. Ritchie was used for the determination of the temperature of deep crevasses, and proved to be very serviceable. A trip on the inland ice was described, and the speaker closed with a comparison of the natives of Greenland with those of Labrador.

Professor Barton spoke briefly of the geological work of the expedition. No evidence of present waning of the ice sheet could be found. The crevassing of the glaciers extends far back into the inland ice. This, with the vertical edges of the ice cap, makes the approach to the inland ice very difficult. Ample evidence was obtained that the ice sheet had extended at some former period much farther than at

[1] See this volume, pp. 56-132.

present in Greenland, and evidences of glacial action were observed also in Labrador.

At the close of Professor Barton's remarks the President thanked the speakers, and the Society adjourned.

WEDNESDAY, November 18, 1896.

A special joint meeting of the SOCIETY OF ARTS, with the Boston Society of Civil Engineers was held this day in Chipman Hall, Tremont Temple, with Professor Swain, President of the Society of Civil Engineers, in the chair.

There being no business, the President introduced Mr. E. L. Corthell, of New York, who read a paper on "The Tampico Harbor Works, Mexico, with some remarks upon the Mouth of the Mississippi River."

Mr. Corthell began by referring to a paper that he had read ten years ago before the SOCIETY OF ARTS, and he reaffirmed his opinion that the Edes Tehuantepec ship railway is practicable. He then spoke of the importance of Tampico as a seaport, and of the hindrance to its development caused by the dangerous bars at the entrance to its harbor. In this connection he described the country through which the railroad had been built from the Mexican Central Railroad to Tampico, and paid a high tribute to the daring and skill of the engineers who constructed it. Turning to his own work at Tampico, Mr. Corthell described the harbor works, and the method of their construction. The works consist of two jetties, 1,000 feet apart, running parallel for a mile and one third into the Gulf of Mexico, one from each side of the mouth of the Rio Panuco. The first operation in the construction of the jetties was to build a double track railroad trestle along the line of each jetty. From these trestles the mattresses composing the jetties were sunk. The mattresses were peculiar. They were built while suspended under the trestle, above the reach of the waves. They were 60 feet long, 84 feet wide, and about 7 feet thick. First a strong frame was constructed, then the brush was added, and then when all was firmly bound together, the mattress was lowered to the surface of the water, and quickly sunk by stones dumped from cars upon the trestle. The slopes of the jetties were steeper inshore, and more gradual further out. The effect of the jetties was seen very soon in the deepening

of the channel, and the disappearance of the dangerous bar. In closing, Mr. Corthell spoke of the beneficial effects of the Mississippi jetties, and of the danger which now threatens those works from their being out of repair. The paper was illustrated with many beautiful lantern views.

At the close of the paper Professor Swain thanked the speaker in the name of the two societies, and the meeting was adjourned.

THURSDAY, December 10, 1896.

The 492d meeting of the SOCIETY OF ARTS was held this day at the Institute, Mr. Blodgett in the chair.

The records of the last two meetings were read and approved.

The Secretary read a letter from the Pasteur Monument Committee of the United States, asking the coöperation of the SOCIETY OF ARTS in its efforts to obtain subscriptions for the erection of a monument to Pasteur in Paris.

The chair then introduced Mr. Henry C. Mercer, Curator of the Museum of American and Prehistoric Archæology in the University of Pennsylvania, who read a paper on "Cave Hunting in Yucatan." The speaker began by showing how caves furnish the key to the state of culture of prehistoric people, and then spoke of the country and present inhabitants of Yucatan, and of the remains of former civilization there. The caves of Yucatan differ from those formerly inhabited by man in Europe and North America, in that they open from the top. They probably would not have been inhabited if it were not that they often contained the only supply of water. Excavations in over twenty caves led to uniform results. The stratum forming the floor of the cave is about a foot thick, and was found to contain fragments of charcoal, pottery, and bones of recent animals. The red earth under this contained some remains of animals, but excavations through to the solid rock beneath showed no trace of the presence of man. The prehistoric culture of Yucatan was not developed there, but came from abroad. At the close of the paper Mr. Mercer showed a large number of views of caves in Europe, the United States, and Yucatan.

The President thanked the lecturer for his very interesting paper, and the Society adjourned.

ROBERT P. BIGELOW, *Secretary.*

THE APSE OF ST. SAUVEUR, CAEN.
From photograph by Mieusement.

THE SUMMER SCHOOL OF ARCHITECTURE FOR 1896 IN SOUTHERN ENGLAND, NORMANDY, AND TOURAINE.

By ELEAZER B. HOMER, S.B.

Read October 22, 1896.

As the great steamer Cestrian backed slowly from the East Boston pier the Technology yell awoke the echoes among the wharves and elevators, and for a time rivalled the deep voice calling for right of way into the harbor channel. The first section of the M. I. T. Summer School of Architecture had at last started on its way across the Atlantic, and its one thousand miles of bicycle travel in Europe. A new departure for American schools was being attempted, and excellent results were expected from the proposed combination of study and healthful exercise. But only in the method of moving the party of students from town to town, was the attempt a new one.

The making of short excursions to interesting buildings and towns, has long been considered an essential part of an architectural student's education. Years ago, when books were few and methods of photographic reproduction unheard of, technical knowledge could only be acquired through personal visits to existing buildings, and through laborious efforts, with pencil or brush, in transferring upon paper the student's impressions of the masterpieces of architecture.

To-day the necessity for travel and close observation does not seem, at first sight, as imperative as in times gone by; for the foreign masterpieces are now brought within the reach of every one, through our public and technical libraries and the modern processes of illustration. The careful examination of books and photographs alone, however, gives only a limited idea of the true appearance of a building, for the more or less correct representation upon paper necessarily fails to express the real values of scale, broad surfaces, and detail, values that can only be understood by inspection of the buildings themselves.

The Summer School of Architecture was accordingly established at the Institute, in order that its work might supplement the regular winter courses. This out-of-door study has proved to be of the great-

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18

GROUP AT HAMPTON COURT.

Enlarged from photograph by E. B. H.

MEMBERS OF THE M. I. T. SUMMER SCHOOL OF ARCHITECTURE, 1896.

1. F. NEVIN.
2. F. M. MANN, Instructor.
3. F. L. HARLOWE.
4. R. L. FULLER.
5. M. F. EWEN.
6. A. H. SPAHR.
7. A. D. SPIESS.
8. C. K. B. NEVIN.
9. D. D. CASSIDY.
10. E. S. VANGORDER.
11. W. D. BRADLEY.
12. H. CUMMINGS, JR.
13. H. D. RAWSON.
14. A. W. JACKSON.
15. F. B. HEATHMAN.
16. J. H. WILLIS.
17. F. H. KEISKER.
18. E S. DODGE.

Not included in photograph.

PROF. E. B. HOMER.
O. C. HERING.
F. N. LEBARON.
W. C. POTTER.

est value, for, aside from the spirit of good fellowship that always adds so much to the pleasure of the traveler, one learns to appreciate architecture as it exists in solid form, and soon gains a clear idea of the relative proportions and importance of the works visited.

In past years the summer work has been confined to the study of buildings and details of the Colonial architecture of our New England States. We possess much that is original and beautiful in the simple dwellings of our old seaport towns, and as these buildings are rapidly disappearing we have made an attempt to preserve at least a small part of the best material by means of measured drawings, sketches, and photographs. But such study, although of great benefit, has heretofore been mainly limited to wooden buildings of comparatively small size, and does not give the broad knowledge of style that all students of architecture should possess. The history of Architecture includes the buildings of America, as the application of older forms to the new conditions of a new country. As such, our American work cannot be perfectly understood until one has become at least partially familiar with European architecture.

An important step, therefore, was taken last spring when it was decided to change the scene of our summer's work from New England to a limited section of France, and to supplement the winter's indoor studies by an excursion among the interesting buildings of the south of England, of Normandy, and Touraine.

Our party included twenty students from the third and fourth year classes, in charge of two instructors. The journey was made on bicycles, partially on account of the expense of railway travel, but principally in order to afford an opportunity for intimate acquaintance with local architecture. By this means a little over 950 miles were covered during our fifty days on land, and much was seen that is not revealed to those who travel bv rail alone.

The route was arranged to include the principal towns of Normandy and Touraine, two of the most interesting architectural sections of France, while a short excursion in England was planned in order to give a comparative view of the architecture of the two countries. Detailed maps, covering the proposed route, were imported early in May, and the selection of the roads from town to town, with the plotting of the route upon the English Government Ordnance maps and the thirty-nine sheets of the Carte de la France, consumed quite a little time in the way of preparation. These maps were taken with us, and

through their assistance the selected route was followed with very little difficulty or need for variation.

We were unusually fortunate in having only a few days of bad weather, so that engagements made with hotels were kept without a break throughout the entire trip. Good hotel accommodations for a party of twenty-two can be obtained in few towns without due warning of from two to ten days, but the advance letters sent to all hotels from America, and the telegrams despatched a few days before our arrival, not only secured as comfortable quarters as could be had, but also insured much lower rates than the regular charges for transient guests. It was not possible, however, to obtain room for the entire party on one steamer, so the first section sailed from Boston June 3, on the Leyland freighter Cestrian, and the second section, June 6, on the Gallia, of the Cunard line.

Both parties traveled by rail to London, where the actual wheeling tour began, and Liverpool, Chester, Shrewsbury, and Oxford were visited on the way. Every one visits Chester, and the city is so accustomed to receiving Americans that its buildings have a prosperous and ready-for-visitors air that suggested the intentionally picturesque appearance of the World's Fair Plaisance. It being Sunday, we seemed to meet all the young people of the town during our morning walk around the walls, but in the afternoon the beautiful choral service in the old cathedral gave us an entirely different impression of the modern life of the town.

Shrewsbury, also, possesses much of its old-time half-timber architecture, which does not offend by the presence of too much fresh paint, and therefore seems older and more attractive than the more ambitious buildings of Chester. The hill on which the old town is built is surrounded on three sides by the picturesque Severn, and along its shores the great rows of lime trees form promenades that far excel those of the famous English gardens at Rambouillet, or any others that I have seen of similar character. We were comfortably housed at The George, and after our evening tramp through the old part of the town, were well satisfied that our quarters were quite superior to those offered by either the String of Horses Inn or The Headless Woman, although these houses displayed signs of far greater antiquity.

At Oxford, all the students were particularly charmed by the quiet dignity of the college buildings, but, much to our regret, our short stay only gave us a glimpse of the outward side of English college life.

Meanwhile, our American bicycles had been journeying by steamer directly to London, where, after five days of interesting but tiresome sightseeing, the wheels were unpacked and put together. Bundles of wearing apparel and drawing and photographic materials were then securely strapped on, and all was ready for the start. The morning of the 19th saw the party on board one of the Thames steamers en route for Putney. This proved to be a good way of leaving the city, as the busy London streets were avoided, and we began riding in comparatively open country.

On this first day, lunch was obtained at Kingston on Thames, and Hampton Court Palace was visited. After looking through the great palace, its extensive picture galleries and gardens, sketches were made of interesting doorways, chimneys, and bits of brick detail. It was found that permission to sketch should have been obtained from the Board of Public Works in London, but the courteous superintendent of the palace gave permission for outside sketching, also accompanying the party to the old Cardinal Wolsey kitchen, and the famous tennis court, pointing out many interesting things that we should not otherwise have seen.

Before leaving Hampton Court a photograph was obtained of eighteen of the twenty-two members of our party, the enlarged photograph on page 8, giving a very good idea of the way in which we traveled and the amount of baggage carried. It is particularly pleasant to look back to this picture, taken on our first day out, for it shows that all the members at one time possessed coats, bicycle lamps, and a few other things that were afterwards discarded. It is also unique in that it shows thirty-six American tires without a single puncture. Six days after, we counted ten punctures on one tire alone.

On this and the following day we traveled over the famous old Portsmouth coaching road, leaving it after passing Guildford, to make a side trip to the little Norman church at Compton. At Guildford we climbed the steep incline of the High Street, passing under the great overhanging clock of the Town Hall, and visited Archbishop Abbot's Hospital, a building similar in style to much of the brick work at Hampton Court. We enjoyed our rest in the ancient dining room or kitchen, seated around an old tradesman who told us stories of the customs of the place. Tempted by the good coast down High Street, we rode too far down, and then climbed the wrong hill in search of

Guildford's old Norman castle, now situated in the public garden of the town. The ancient keep of the castle rises about seventy feet above the surrounding ruins, and is built of regular courses of herring-bone work, flints, and sandstone that can all be clearly identified. After a time, finding the right way out of town, we passed through a delightful bit of English country, bowling along over splendid roads

HIGH STREET AND TOWN HALL, GUILDFORD.
Photographed by E. B. H.

until the cobblestones of Godalming were reached. All the way along the route we passed picturesque cottages, thatched and half-timbered, that repeatedly tempted our amateur photographers. A comfortable night at the hospitable Angel at Godalming closed our second day. The following morning sketches were made of the picturesque court-yard of the inn, our landlord's strawberries duly appreciated, the Town Hall visited in company with the senior alderman of the town, and then wheels were brought out for the ride to Compton, Elstead, and Waverley Abbey, on the way to Farnham.

The little church at Compton possesses a particularly interesting Norman interior, and we secured a few sketches of capitals, and photographs of the primitive timber roof. The kind old lady who showed us the church could not understand why we did not know her son who had gone to America, but at last, finding that he was located somewhere in Kansas, we tried to explain a little United States geography,

THE VILLAGE CHURCH, COMPTON.

but with only indifferent success. After our lunch at Elstead, where our landlord of the Golden Fleece, who also dealt in grain, hay, and coal, personally waited on table in his shirt sleeves, we climbed the long grade to Crooksbury Common, and, later on, descended into the valley of the River Wey, stopping to visit the ruins of Waverley Abbey. The remaining walls of the abbey are scattered over broad meadows, in which the haymakers were busy at the time of our visit, and show that the ancient Cistercian monastery must have been very extensive. Little now remains, although the vaulting under the chapel is still in fairly good condition.

Our way for the next day ran almost parallel with the Alton

branch of the London & Southwestern Railroad, and, as expected, passed through open, rolling country quite in contrast to the picturesque portion of Surrey just passed. But at the village of Chawton we had a diversion, and cameras were brought out to photograph a little Italian boy and lively monkey. The thatched roofed houses of this village were particularly attractive. Taking the wrong fork of the

OLD AND NEW TRUSSES OVER THE NAVE OF WINCHESTER CATHEDRAL.

Photographed by E. B. H.

road, we had to inquire our way of one of the bright little fellows of the village school just out for recess, and then journeyed on through Abbotsford and the Worthy's, down the beautiful valley of the winding Itchen, until toward evening we rode into the ancient town of Winchester.

The following morning we visited some of the buildings of the famous old town, and, after looking through the cathedral, were particularly fortunate in obtaining permission to climb the long ladder leading to the nave roof, where the obsolete form of roof truss is being

replaced by a stouter modern construction. The old roof does not all date from the eleventh century, but the great tie beams, upon which the two men are sitting, have been retained from the earlier truss work of the time of William the Conqueror, and will be carefully preserved in the new roof. As they are too short for the present form of truss, and are also worm-eaten and decayed at the ends, only the middle part of solid wood is to be saved. Bits of the old oak and the

DOUBLE ARCH AT ST. CROSS HOSPITAL CHURCH, WINCHESTER.

large wrought-iron rails that fastened the lead covering were quite in demand by members of our party, but few relics survived the Normandy hills and fewer still are now treasured in America.

As we walked through these trusses, above the great recesses of the fourteenth-century stone vaulting which forms the true ceiling of the interior, we could hear the organ beginning the morning service, and therefore had to descend long before we had finished our notes

and researches. We had intended to spend more time in this city, but an extra day in London had to be made up by cutting at Winchester, so we were obliged to leave without doing it justice, as far as sight-seeing was concerned. But we remember very pleasantly our stop at St. Cross Hospital, founded 1136, just outside of Winchester, where, after entering the quiet quadrangle, surrounded by the houses and the church buildings, we were shown through the church by a delightful old gentleman, one of the thirteen old men who live at the hospital. The church has remarkably rich late Norman decorations in the interior and also has a unique double arch in an angle at the rear. As can be seen, the original doorway under this arch is now filled in. The attractions here were so great that we arrived at Romsey at quite a late hour. After an unsatisfactory dinner, we spent a short time at Romsey Abbey, then some of the party took train for Salisbury, while the others, with a strong wind behind, quickly covered the eleven-mile ride to Southampton.

Taking the night boat from Southampton across the Channel, we found, after a quiet passage and good night's rest, that we were well into the harbor of Havre, and by eight o'clock we were all through the custom house and searching for breakfast. Our party attracted much attention at Havre, and we were all kept busy answering questions while waiting for money and letters.

Our English Cyclists' Touring Club badges served us well at Havre, for, after showing them, we were permitted to pass the custom house without any question as to duties. We also found in England that the Touring Club discounts were readily given at all the hotels, and that our tickets made quite a saving in our daily expenses; in some cases as much as twenty-five per cent. on the regular rates.

But trouble had already begun with our bicycles, as our American tires were not heavy enough to stand the flint roads. For this reason our first few days' riding in France was absolutely discouraging. In spite of the splendid surfaces of the roads so many flints were encountered that among our twenty-two men we counted thirty punctures during the four days' riding between Havre, Rouen, and Lisieux. Only a few of the party escaped without striking the sharp flint edges. In fact, several new tires had to be ordered from Paris, for some of the old tires were beyond even the most careful treatment. But shortly after leaving Lisieux we were thankful to find that the flints had disappeared, and we only encountered them again as we neared Paris.

Stopping at noon on our first day in France at Lillebonne, we were surprised to see the extent of the Roman theater and to find that so much of the Roman masonry remains in apparently good condition. On the opposite side of the theater one of the arches still stands, the restored portion on the right clearly showing its construction of tile and rubble work. After mounting the steep side of the valley through which the River Bolbec flows we traversed the rolling upland, following an excellent third-class road. Here, on the steep, winding descent to Caudebec, the first bad tumble occurred, one of the men failing to make a three-quarter curve because of too much speed, but

ARCH IN ROMAN THEATER, LILLEBONNE.

Photographed by E. B. H.

fortunately no bones were broken. A new rim was fitted on over night and all was right again in the morning.

Caudebec is exceedingly quaint, having many little crooked streets and old timber houses, but its church rises above the architectural level of the other buildings and is an excellent example of the rich flamboyant style. After breakfast we watched the "Mascaret," the great tidal wave, sweep up the Seine; and then, with the genial proprietor of the Hotel de la Marine as guide, rode out to St. Wandrille Abbey, where we saw many bits of late Gothic and Rococo architecture under the guidance of a courteous and well-informed priest; then on to Jumièges Abbey, whose magnificent arches and masses almost overpowered us. Jumièges, founded in the 7th century, is one of the best examples of the early heavy Norman style, and one rarely finds

SOUTH TRANSEPT, ST. OUEN, ROUEN.

such an imposing group of ruins. Returning over the branch road about three kilometers, we followed the main road around a wide bend of the Seine, and at last came in sight of the abbey towers of St. Georges-de-Boscherville. There we spent some two hours sketching and studying the interior of the church. This is a fine example of late Norman design and construction, but, as with all the recently restored churches in France, the interior seems a little cold because of the freshness of the stone and too great care in jointing the stonework. We arrived near Rouen just before sunset, in time to have a magnificent view of the entire city, with its great amphitheater of surrounding hills, from the heights of Canteleau.

Rouen was crowded, in preparation for the great horse races that were to be held the next Sunday afternoon, but good accommodations were found at the Hotel de France on the quay. As expected, it was impossible to do any drawing here, for there was so much to be seen during our short stay that our time was fully occupied in tramping about the city and trying to appreciate the rich Gothic and Renaissance architecture for which Rouen is so justly famous. St. Ouen impressed all by the magnificence of its south transept, rich lantern, and grand interior. The trip around the triforium and over the roofs was particularly interesting, the unconsciously mysterious and impressive manner with which our guide pointed out the beauties of the building adding greatly to our enjoyment.

Our ride to Elbeuf, Brionne, and Bernay proved to be a hard day's journey. We crossed several rivers and the hills lying between, but notwithstanding many punctures and consequent delays, we all arrived in time for dinner. After sipping our coffee and singing songs in the court of the hotel, all were glad to retire early.

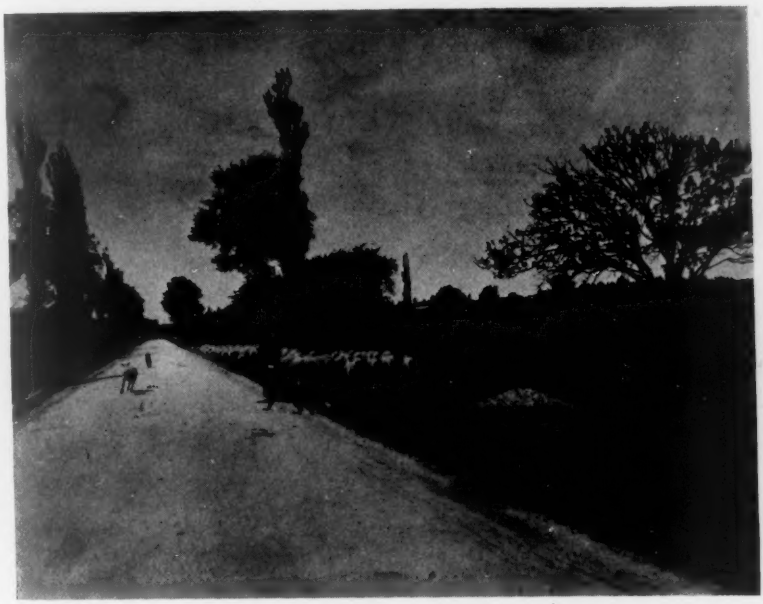
Lisieux was reached on the following day, and there we remained for two days, making sketches of the old timber houses and of the interior of the cathedral. This quaint town is full of woodwork of the fourteenth to sixteenth centuries, and one cannot walk in any direction near the Grande-Rue without finding splendid examples of the carpentry of this period. One well-known house in this street is particularly attractive, and has the reputation of drawing a sketch from every artist or architect who visits the town. It is needless to say that we all felt its influence. The most picturesque street is, perhaps, the Rue au Fevres, where we found the famous "House of the Salamander," built in the time of Francis I, and having the richest carved front in the town.

OLD HOUSE, GRANDE-RUE, LISIEUX.

On leaving Lisieux we arranged to lunch at the village of Crevecœur, but arriving there we found a village fair in full swing and the hotel unable to accommodate all its patrons. After two hours' patient waiting we at last obtained a miserable lunch and departed firmly resolved to make future arrangements only in the larger towns, for even a village fair loses its attractions when one is really hungry.

The excellent road leading to Caen was then passed over in the face of a hard head wind, the last member of the party arriving just in time to escape the heavy rain that continued all that night and the next day. This is a very good example of the national roads of this section (see next page), for though running for miles through the open country they are kept in perfect condition, the surfaces being even superior to many of our park roads. Our day at Caen was wet

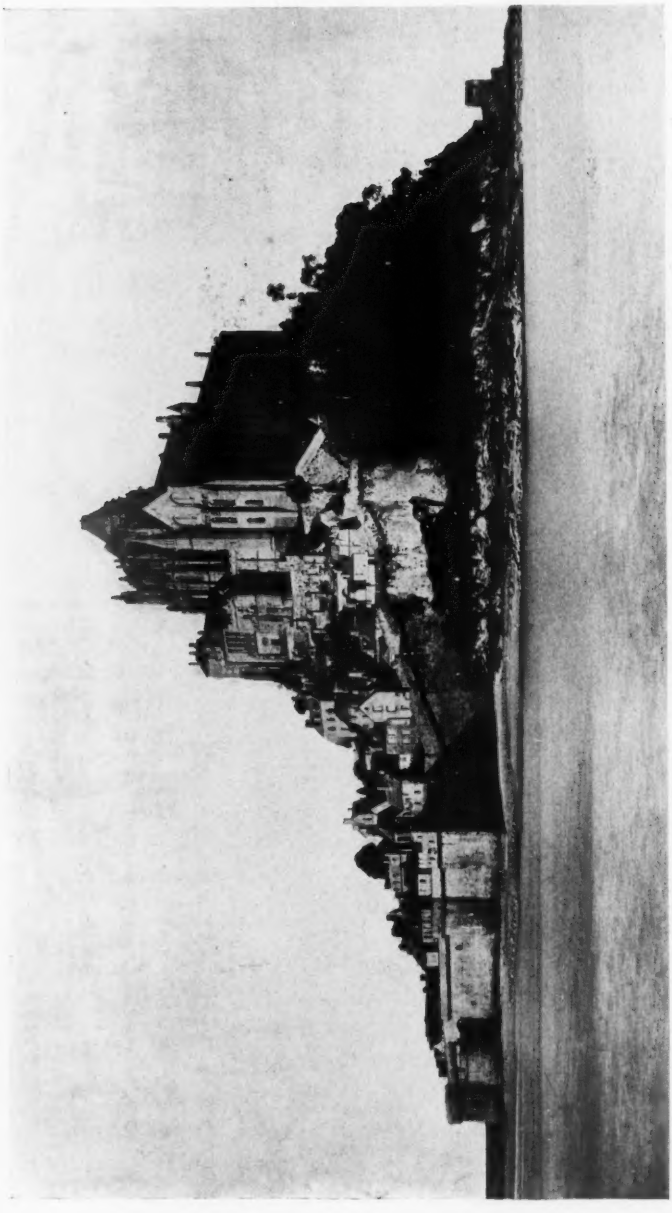
and uncomfortable, but while sketching in the interior of the church of the Abbaye aux Dames the morning passed quickly. St. Nicholas, of the eleventh century, and St. Stephen, built by William the Con-



On the National Road Between Lisieux and Caen.
Photographed by E. B. H.

queror, were visited, and notes made in St. Stephen of the peculiar sexpartite vaulting of this transitional period.

St. Nicholas is now used as a government storehouse for hay and grain, and visitors are not admitted ; but it was found that a franc used in the right way removed all barriers. In the same city the ruined Old Church of St. Etienne is also now turned into a storehouse, and many fine bits of stone detail are deposited there for the Caen Antiquarian Society. Several drawings of these fragments were secured during the time it was necessary to remain under cover. The delicate late Gothic apse of St. Sauveur is one of the most graceful Gothic designs with which I am acquainted, but it is only one example taken from many beautiful and impressive buildings that enrich this Norman city.



THE TOWN AND MONASTERY OF MONT ST. MICHEL.

We finally started for Bayeux with clearing skies, and after a delightful run along the by-roads leading to the villages of Norrey and Audrieu, a little south of the main road, spent the night in the city still famous for its old tapestries. At Bayeux we changed our daily program, deciding to do our sketching in the morning and ride in the afternoon, as the fatigue of riding prevented the best work. This arrangement was followed for the next few days, and St. Lô, Coutances, Granville, and Avranches were in turn visited, the distances between these towns requiring only a small part of each afternoon.

The Fourth of July was spent at St. Lô, and there on the Place in front of the cathedral, high above the city, we sang patriotic songs by the light of a small bonfire of straw and leaves and tried to think that we were helping America celebrate her noisy day.

All eyes were now turned toward Mont St. Michel, and we hoped to see the great rock from the top of the cathedral at Coutances, but as the horizon was hazy the first glimpse was obtained two days later, as we passed over the hills at Genets on the northern shore of the bay on the way to Avranches. We could, however, see Granville from the top of Coutances Cathedral directly over the tower of St. Pierre, and late in the afternoon, after a quick ride over excellent roads, we arrived in time to take a refreshing afternoon bath in the blue waters of the Atlantic.

At Mont St. Michel, after wheeling along the causeway and passing the gauntlet of hotel criers, we were comfortably housed at the Poulard Aînè, taking the whole of the Maison Blanc for our quarters. A delightful two days was spent in this famous place. Thanks to our permits from the French Government, the keys of the monastery were given us and we could wander at will from the dark dungeons cut in the solid rock to the rich flying buttresses of the Gothic church. Sketches were made in the Salle des Chevaliers, and during the quiet afternoons many bits of picturesque stonework were transferred to the drawing paper. In the evenings long walks were taken on the sands, as it was the season of low tides. The magnificent effects of the setting sun on the ancient walls, and the glorious views of the sunsets from the walls themselves, will long be remembered. Mont St. Michel was a climax to which we had unconsciously looked forward, and our parting cheer for the Poulard Aînè closed a very pleasant section of our summer trip.

The country south of this resting place is, for architectural stu-

dents, somewhat bare and uninteresting. With the exception of occasional bright spots it was passed over without incident. Fougères possesses an enormous castle of which the outer walls alone remain; but its high walls and numerous towers, and the surrounding old portions of the town, are very picturesque. The greater part of the mediæval walls are now destroyed, but in the lower part of the city the

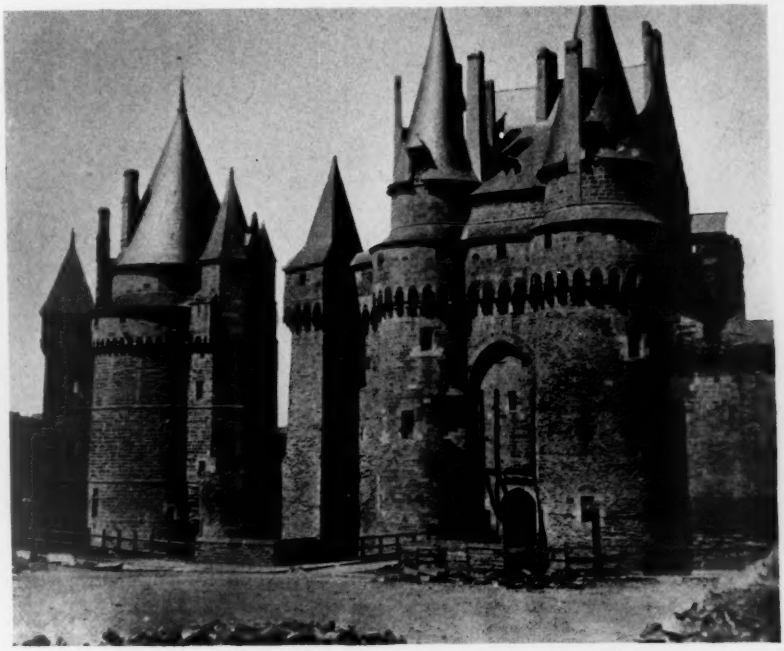
HALL OF THE CHEVALIERS. MONT ST. MICHEL.

old gate is one of the few remaining fragments of this ancient and strongly fortified town.

But as a town Vitré is far more interesting than Fougères, its splendid chateau and fine old houses making it even more attractive than Lisieux. While possessing several streets lined with picturesque wooden houses, it also seems to be a very prosperous modern place, quite in contrast to the slumbering towns visited in Normandy. The chateau entrance is very striking and original. One passes over the drawbridge spanning the wide moat and enters a fairly spacious open court, containing at the farther end a picturesque little building decorated with a good oriel window of Renaissance design. We tried to

obtain a measured drawing of this window, but as it is just back of the modern prison wall we found that the city authorities had to be consulted. The red tape encountered proved to be too much for our short visit. At Vitré the hot weather seemed to set in in earnest and we again changed our riding hours, avoiding the hottest part of the day.

On Sunday, after attending service for a short time at Notre



THE CASTLE ENTRANCE. VITRÉ.

Photographed by E. B. H.

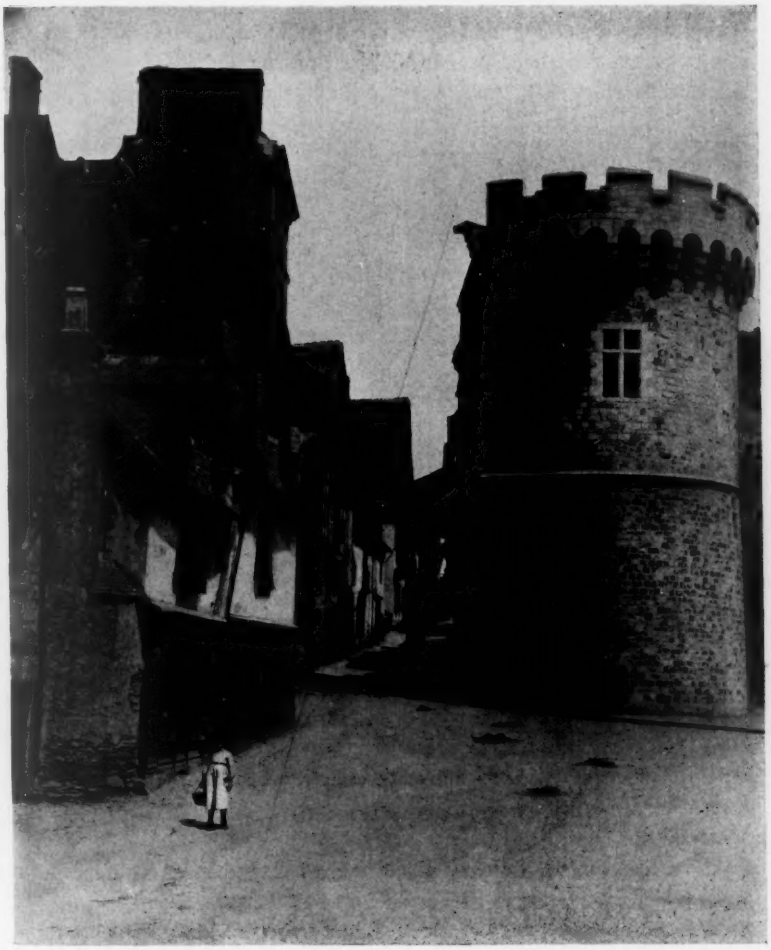
Dame, a Gothic church with a beautiful outside pulpit, a small party wheeled over to the little village of Champeaux, and felt well repaid for the hot ride while visiting the chateau and church formerly belonging to the Chevalier de l'Epinay. The chateau still possesses its wide moat, but the surrounding walls have almost entirely disappeared and the whole place is overgrown with trees. Although the church is about one mile away, tradition says that the buildings are connected by an underground passage used by the family in troublesome times.

ORIEL IN COURT OF CASTLE. VITRÉ.

We certainly saw the top of stone vaulting in the driveway of the chateau, and were told that a hole in the wall, in the crypt of the church, was the other end of the tunnel, but the deep valley and rocky hills lying between the two buildings made us sceptical about the connecting links.

Leaving Vitré early on the morning of the 13th we soon reached

the Château des Rochers, famous as the residence of Madame de Sévigné, and for its gardens planned by Le Notre, the most famous landscape gardener of the seventeenth century.



OLD STREET AT VITRÉ.

We now had two of our longest rides before us, through a country that presented little that was interesting in the way of varied scenery. Village after village was passed on our morning ride to

La Guerche, where we rested during the hottest hours of the day. The afternoon run would have been uneventful if we had not unexpectedly seen the façade of the church at the little village of La Roë.

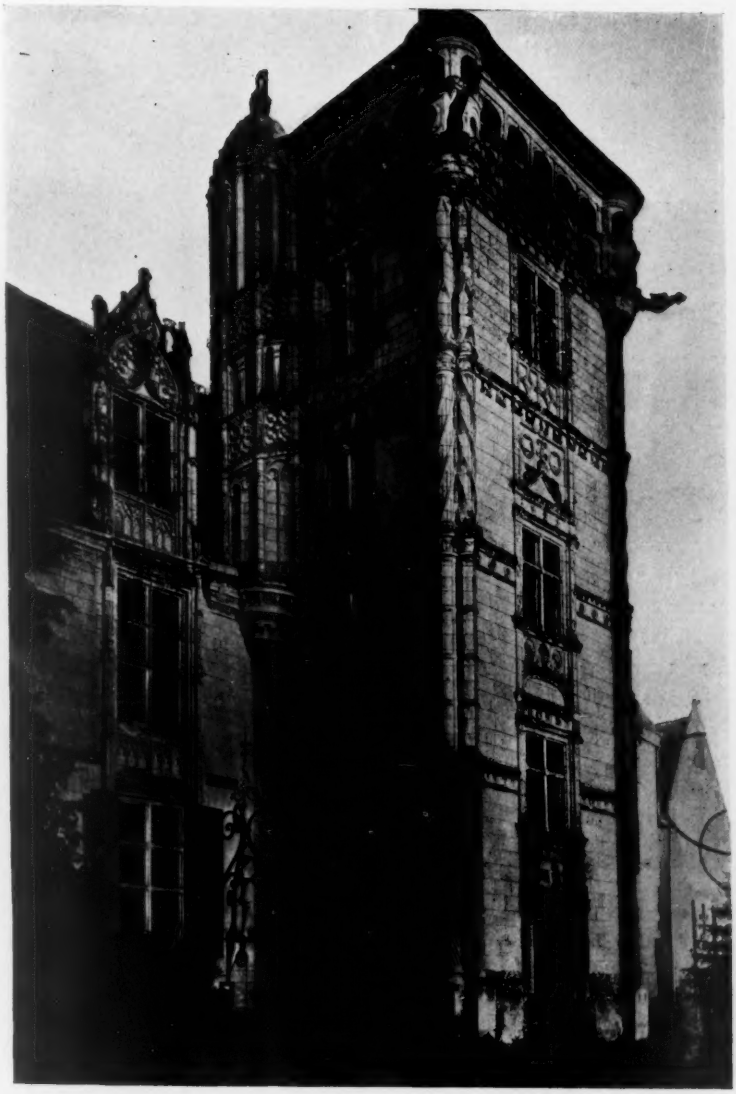
This was our first taste of the rich Romanesque architecture of Anjou and gave us a good idea of the dignified designs common to the southwestern part of France. There are, undoubtedly, some drawbacks to touring by bicycle, but the finding of this architectural gem,

WEST FAÇADE OF CHURCH AT LA ROË.

Photographed by E. B. H.

in such a little, out-of-the-way place as the village of La Roë, made up for all the inconveniences of our ride on that very hot day.

We then pushed along, up and down the rolling hills and even grades of the great national road, traveling due east in a straight line until Château Gontier was reached. In fact, so accustomed to regular and monotonous leg work did we become, that some of us ran through the town and five kilometers beyond before realizing that we had passed our stopping-place for the night. That was the hottest day and



TOWER OF CHATEAU AT CHEMAZÉ.

the longest ride of the trip, but we felt quite refreshed after a swim in the sluggish and not too clean waters of the Mayenne.

The 14th proved to be about as hot as the preceding day. Making an early start the party divided, some taking the direct national road to Angers and others going on a venture about five miles out of the way to see the chateau at Chemazé. We were amply repaid for the side journey, for this chateau possesses some of the best early Renaissance detail. It was our first building of this character and we were soon busy with our cameras. Although we arrived at eight in the morning, and the owner was then at home, we easily obtained permission to visit the larger rooms, thoroughly enjoying our glimpse into the well-arranged half-modern, half-ancient interior. The square tower is particularly beautiful in detail and, combined with the transitional dormers, makes an unusually rich façade for a country house. We climbed the winding tower staircase, admiring the delicate interior carvings as we went, and from the top obtained a fine view of the wide rolling country across which we were traveling.

Leaving Chemazé with many regrets, we wandered through the winding country roads, surprising numerous flocks of geese as they fed by the roadside, until we at last met the great national road. Then it was push up hill and coast down the other side, mile after mile, riding directly south under a broiling sun, until at last we reached the down grade that told us we were in the valley of the Loire and that Angers was not far off.

Our arrival at Angers closed a period of fatiguing riding. We had traveled ninety-six miles in two days, pushing our heavily loaded wheels along monotonously straight roads that seemed to reflect an enormous amount of heat from their white surfaces. We were therefore glad to rest for a day or two at the comfortable Cheval-Blanc, even although Angers did not prove to be as rich in ancient and interesting architecture as we had hoped. The photograph clearly shows the splendid surface of this great road and the rolling, almost level, character of the country. It was taken about ten miles from Angers. The distance from the turn near the horizon to the top of the hill in the foreground was exactly six kilometers, according to the government measurements indicated on the kilometer stones at the side of the road, and it ran over five hills in that space of three and three fourths English miles.

Among the modern buildings of the prosperous city of Angers

NATIONAL ROAD NEAR ANGERS.

Photographed by E. B. H.

only a few relics of the older time still remain. The ancient Tour St. Aubin, now standing alone among the commonplace houses of the modern streets, was once a part of a great monastery which covered a large section of the city. Another fragment of the monastic buildings was discovered some years ago when a wall in the Préfecture was torn down. To-day this mutilated arcade, enriched with early almost barbaric sculpture, is perhaps one of the richest examples of decorative work of the Romanesque period, and is carefully treasured by the city and national authorities. In contrast to this primitive work, the delicate Renaissance detail of the Hotel Pincé (1535) furnishes the other extreme. Situated in the business part of the city, near the post office and theater, it still retains its small garden, which pushes it back from the general line of the shop fronts. Its delicate carvings now seem entirely out of place with its changed surroundings.

But the most interesting building in Angers, from a constructional point of view, is the Cathedral St. Maurice, commenced in the 11th century, as it is one of the transitional examples showing the beginning of the change from the domical vaulting found in cities a little far-

ther south to the developed vaulting of the northern cathedrals. Several photographs were taken to illustrate the peculiarities of its interior, but on account of the uncertain light they were not entirely successful. Angers also possesses a few quaint streets and old modern houses, but much has long been destroyed by the fires that from time to time have swept the town.

Our stay at the Cheval-Blanc was so thoroughly enjoyable, after the indifferent hotels of the towns through which we had passed, that

HOTEL PINCÉ. ANGERS.
Photographed by E. B. H.

about half the party decided to remain in safe quarters, and later on take the shortest road instead of running the chance of a wetting by starting early in the morning of the 16th. The adventurous half only succeeded in reaching the outskirts of the city when the rain descended and the floods came upon us. But we were fortunate enough to escape a thorough drenching by taking refuge in a large modern church, storing our bicycles in an old corn mill near by. After a tiresome wait we donned our rubber capes for the first time

PREHISTORIC DOLMEN. GENNES.

Photographed by E. B. H.

CHURCH OF TREVES-CUNAULT.

and ventured to ride through the flooded streets, quite enjoying the experience until the mud thrown by the rear wheels began to creep up our backs and over our heads, as mud will fly even with careful riding. The sun coming out we were soon forced to discard our capes on account of the heat and travel slowly until the roads were fairly dry. We then had a delightful run over the winding country roads, through vineyards and wet fields, on the way from Brissac to Gennes.

Lunching at Gennes and afterwards climbing the side of the valley to look at its old prehistoric dolmen, a little way out of the town, we were soon running over a smooth and almost level road along the left bank of the Loire. That was a most remarkable afternoon's ride, for the numerous small villages passed, each with its old Romanesque church and quaint old houses stretching along the river banks, gave us a foretaste of the rich architectural treasures of the Loire Valley. Cunault is perhaps the richest of these churches, since it possesses a beautiful tower or primitive spire that is quite in contrast to the plain walls of the other parts of the church. The capitals and paintings of the interior are also particularly quaint and grotesque.

Some three miles before reaching Saumur we discovered a large party of horsemen to the left of our road, and found that the students of the famous Saumur Military School were preparing to cross a branch of the river without boats, and that their instructors and friends were in attendance to witness the attempt. To effect the crossing fodder bags were filled with hay and fastened together by light sticks, and upon these frail rafts saddles and bridles were placed. Not more than four men could sit upon the pile at one time and succeed in keeping their immaculate clothes dry while pulling across the stream. The horses were driven into the river and after more or less encouragement swam across.

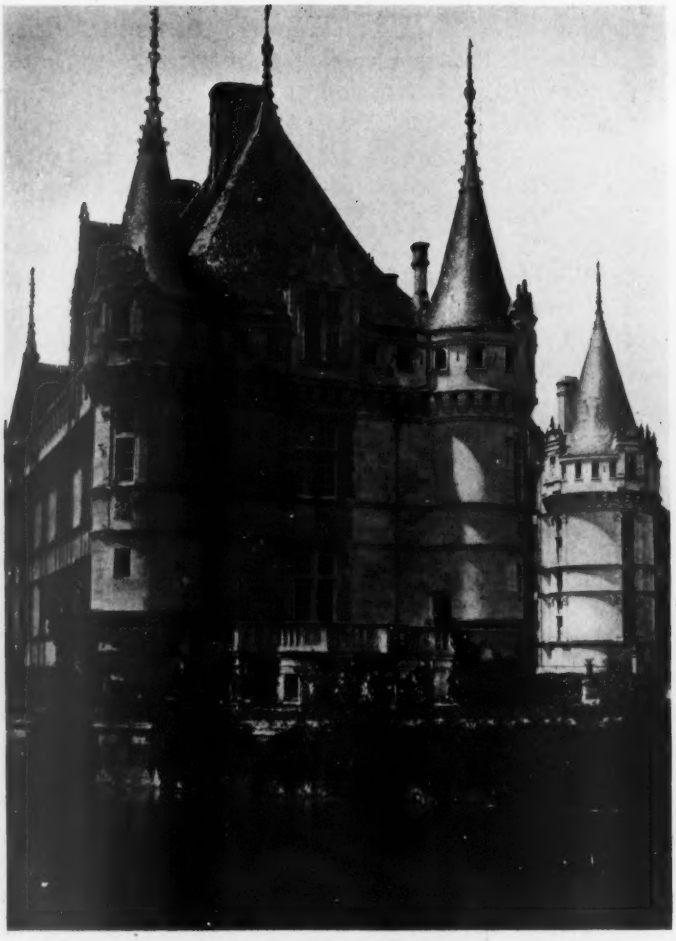
Without staying long at Saumur we continued our ride up the beautiful Loire Valley, stopping at noon at Chinon. Another bad tumble occurred on this run, for one of the men ran into a flock of sheep; or, to be more accurate, the sheep and dog ran into him, and completely ruined his front wheel. Fortune again favored us, however, for although quite a distance from any village an accommodating Frenchman arrived upon the scene in his English dogcart, and, seeing our plight, kindly carried the wounded rider and broken wheel all the way to Chinon. We had a delightful ramble among the ruins of the three castles that crown the hill far above the quaint old houses of

this town, and stood for a time within the walls that once formed the hall where Joan of Arc had her audience with Charles VII. The Château of Chinon is full of surprises, its towers, bridges, deep moats, and underground passages affording endless opportunities for the venturesome traveler. The view of the valley, as we stood upon the edge of the projecting tower with the Vienne far below us, was most extensive and very beautiful in its combination of soft colors, but the view was entirely beyond our cameras.

After climbing the valley and leaving Chinon we encountered the worst stretch of road that I ever tried to ride over. The maps show a third-class road running directly from Chinon to Azay-le-Rideau, but I wish to warn any one from attempting that route, for the road is not only abominably hilly but for miles is covered with loose gravel and broken stone. Riding sometimes in a narrow rut, sometimes on the grass and little side paths, it was a wonder that our machines were not completely disjointed by the constant wrack and strain. Azay was finally reached and the rough experience soon forgotten in the interest awakened by the charming chateau.

The homelike, comfortable character of Azay is in marked contrast to the more formal appearance of the larger Renaissance chateaux, and our day spent in sketching this delightful building is one of the pleasantest that we remember. We were fortunate in gaining admission to the interior and in having an opportunity to see some of its rich historical treasures. The large salon on a lower floor, and the bedroom of Francis I directly above, were two of the most interesting rooms. The views from the windows of this room also showed the work of the landscape gardener to the best advantage. The great amount of interesting Renaissance detail that this chateau possesses is especially attractive, the delicate treatment of doors, windows, and dormers adding greatly to the charm and beauty of the building. Riding on up the wide valley, close to the banks of the Loire, we crossed the splendid stone Pont de Tours and were at once in the prosperous modern city.

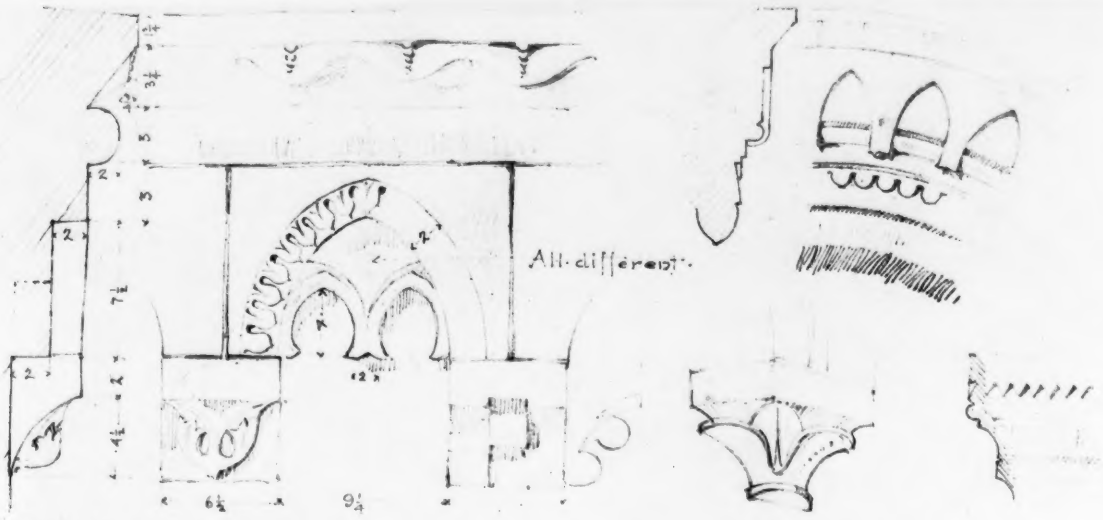
One needs to know Tours thoroughly in order to locate its remaining historical buildings among the host of modern houses. Henry James's little book was here far more useful to us than our guidebooks, and thanks to its directions, we discovered a very delicate fragment of Renaissance design near the modern church of St. Martin. Only five or six of the beautiful arches of the arcade of this convent now remain, and these are in a mutilated condition ; but as the "Lit-



CHATEAU OF AZAY-LE-RIDEAU.

tle Tour in France" justly states: "Such a piece of work is the purest flower of the French Renaissance; there is nothing more delicate in all Touraine."

Leaving Tours Sunday noon, we had another delightful ride through the valley of the Indre, where we were many times forced to stop and gaze at quaint pastoral scenes along the banks of the



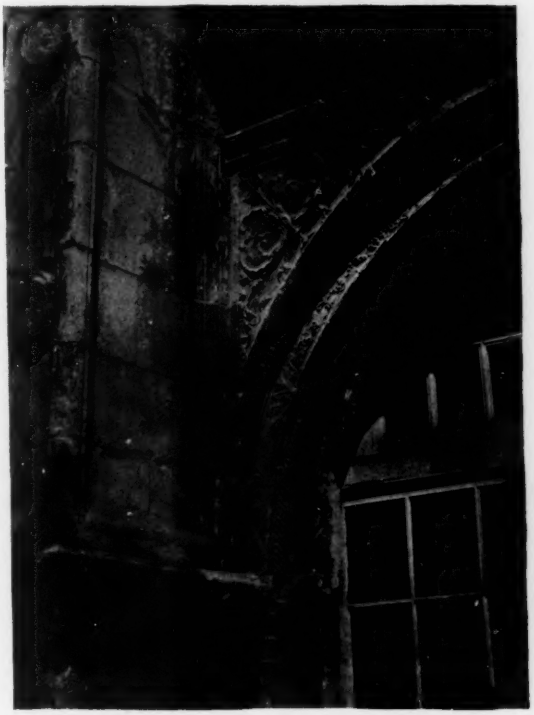
Some details in the Chapter Room.
Church of St. Martin.
Bocherville. June 26th 96.

A.H. Spahn.

W. E. Bradley.
Chevy Chase
July 22 1894
Photo-Gravure Co. Boston

river. These river roads are particularly attractive. Always bordered by green fields or the welcome shade of tall trees, their winding surfaces are in marked contrast to the monotonous national roads which traverse the open hills without variety.

Loches was reached without further incident, and the following day we visited the quaint Church of St. Ours, the castle, and the



ONE OF THE ARCHES IN THE CONVENT NEAR ST. MARTINS CHURCH. TOURS.
Photographed by E. B. H.

palace. St. Ours has two peculiar conical vaults over the nave that give the church a very unusual appearance. Viewed from the street the roofs are picturesque and perplexing, but seen from the top of the castle walls the whole arrangement of the church is at once apparent. This castle is not only used as a prison to-day — the guide locking the door after you have entered — but possesses some of the

strongest and darkest subterranean dungeons of any of the castles of the Middle Ages. In its famous Martelet Tower, Ludovico Sforza, Duke of Milan, was confined for nine years.

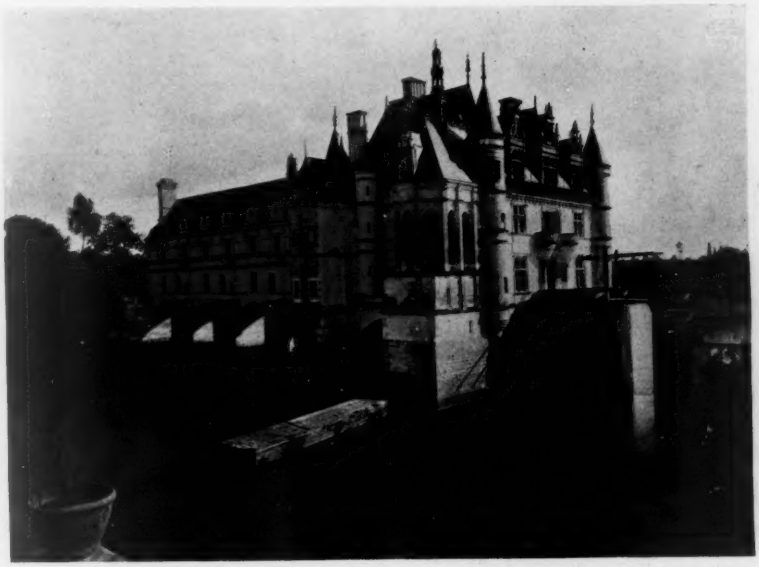
The first break in our numbers occurred at Loches, for one of the students was obliged to set out for Germany, and later on another, who was too sick with an attack of malaria to enjoy riding, decided to cover the remaining ground by train. At the departure of the even-

CHURCH OF ST. OURS. LOCHES.

Photographed by E. B. H.

ing train the students stirred up the town, tramping to the station to the inspiring tune of "Marching thro' Georgia," played upon cornet, cymbals, snare, and bass drum, all hired from a neighboring cheap theater for the sum of five francs. The departing student marched in state, with bicycle and valise carried in front, and arriving at the station was promptly assisted by the guard into a first-class compartment, for which he had to pay excess fare upon arriving at Tours, as he could only show a third-class ticket.

Leaving picturesque Loches behind, we crossed the hills to Chenonceaux, racing before a coming storm at a scorching pace; but the storm which we could see behind us passed down the valley that we had just left and we arrived at Chenonceaux without the expected wetting. We were here allowed to go all about the grounds and make sketches of the exterior of the chateau, but permission could not be obtained to visit the interior or the great picture gallery which extends almost across the river. The whole building stands upon



CHATEAU OF CHENONCEAUX.

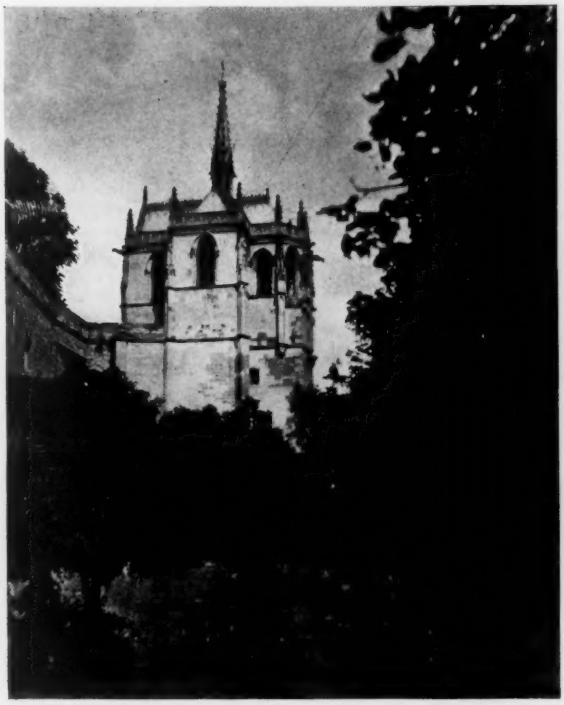
piers built in the bed of the Cher, and entrance is obtained only by the drawbridge in front of the picturesque tower that serves as an advance guard for the main building. Around the chateau the walks through the woods are very carefully laid out, but the large garden is too symmetrical and conventional to be pleasing.

Before leaving Chenonceaux we discovered that we had not money enough in the party to pay the hotel bill, our expenses through this section being about 250 francs, or $50, each day, so as some of the party wished to go on to Amboise six of us made a night ride, one

starting by train for Blois early the next morning, obtaining the necessary funds, and returning in time to settle all accounts before the hotel people discovered that the treasurer had barely enough money to tip the waiters. Carrying our money by letter of credit and American Express notes, we should have fallen by the wayside quite often if each man had been obliged to look out for himself, but united we were strong enough for any emergency.

VALLEY OF THE LOIRE FROM THE TOP OF THE GREAT TOWER, CHATEAU OF AMBOISE.
Photographed by E. B. H.

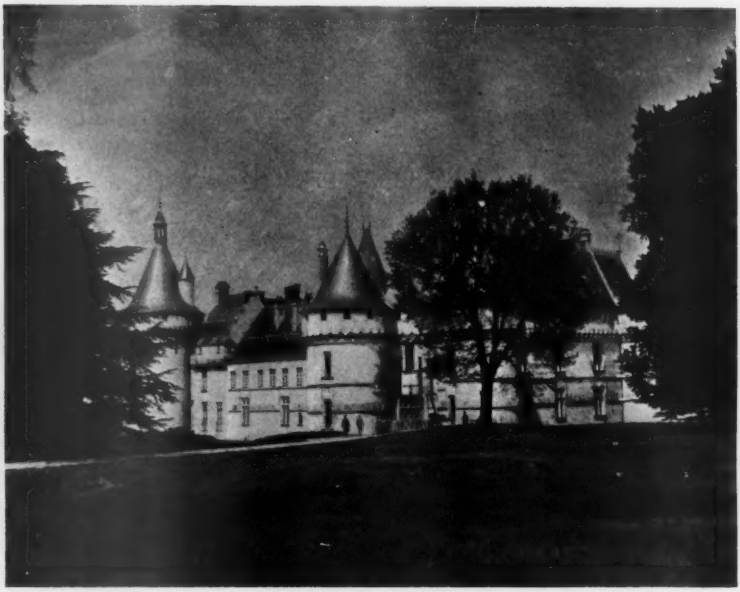
The chateau at Amboise is now undergoing extensive restorations, so that we could not clearly see the whole building. In the center of the walls, overlooking the river, rises one of the massive towers 130 feet high, containing the great spiral plane by which horses and carriages reach the level of the courtyard of the chateau. From the street of the town this tower rises far above the surrounding houses, while from its top a fine view is obtained of the wide valley; but the black and white of the photograph does not do justice to the panorama, since it leaves out all the soft effects of green foliage and blue water which the painter alone could suggest.



ST. HUBERT'S CHAPEL. AMBOISE.

Photographed by F. B. Heathman.

The gem of Amboise is the little chapel of St. Hubert, perched high on the southwestern side of the wall. To reach it one passes through the great inclined tunnel in the angle of the wall, and arrives by various passages on the general level of the chateau grounds. The commanding location of the chapel is seen best from the top of the large south tower, the enormous sub-structure of the walls lifting the terrace high above the houses of the town. This little building, without any reservation, is externally one of the most beautiful examples of Gothic design, for although attached to the massive stonework of the wall it shows a delicacy and refinement that is almost marvelous. The rich doorway, with its bas-reliefs illustrating scenes from the life of St. Hubert, is also one of the gems of Gothic sculpture.



CHATEAU OF CHAUMONT.

Photographed by E. B. H.

Crossing the river on leaving Amboise, we took the road under the hills on the right bank of the Seine and found many charmingly situated chateaux of a smaller type. Of these, Du Plessis was one of the most interesting. Turning off this road at Onzain, we crossed the wooden bridge over the Loire and leaving our wheels at the hotel climbed the long walk to the chateau of Chaumont. The courtyard of this vigorously designed building commands a wide view of the valley that rivals the view at Amboise. The rooms to which we were admitted were very richly hung with tapestries and full of souvenirs of Dian de Poitiers and Catherine de Medici. Remaining on this left side of the river we soon covered the distance to Blois, and passing over the highly crowned stone bridge were soon at our hotel near the famous chateau, the principal building of its class in France.

So much has been written about Blois that I will not attempt here to describe its beauties. The Francis I wing is justly famous for its exterior, and for its richly carved court façade with its elaborate spiral staircase. But to me the quieter Louis XII side of the court is far

more pleasing and more thoroughly graceful in architectural effect. It is one of the few buildings that one wants to sit down before and quietly let it tell its own story.

After two days at Blois, principally spent in the chateau, we journeyed on, spending a short time among the complicated roofs of the vast, barren chateau of Chambord. The night was spent at Orleans,

THE LOIRE AT CHATEAUDUN.

Photographed by E. B. H.

and from there began the most fatiguing ride of the trip, the thirty-five miles to Chateaudun, through monotonous grain fields, against a heavy head wind. That all were well tired is shown by the fact that our party of young men, hardened by forty days' continuous riding, turned in for a nap directly after obtaining a much-needed lunch. The old, deserted castle of Chateaudun was wandered over late in the afternoon and all were impressed by the desolate character of its great rooms. This castle possesses a donjon of the 12th century, having a remarkably substantial timber roof, and also shows much rich Renaissance detail around the interior courtyard.

The Loire is here quite small and unimportant, although very pretty just as it enters the town near the base of the chateau, but it is hard to think that the beautiful river at this point is particularly filthy. The washing stands seen by the riverside everywhere in France are quite common in this town. There is, however, such a suggestion of sewage in the discolored waters, that one wonders how the laundry can come home as clean and fresh as it always appears.

Lunching at the village of Bonneval, where it seems that Americans are rarely seen, we later on reached Chartres. There we spent our time principally in the magnificent cathedral, the most imposing Gothic building in France; but I can only very briefly mention its grand interior, beautiful towers and porches, or its wealth of magnificent stained glass.

MAIN AVENUE OF THE GARDENS. PALACE OF VERSAILLES.

Along the valley of the Villette we had our last picturesque ride, and at the charming chateau at Maintenon obtained permission to enter the gallery of the Noailles family portraits. Leaving this beautifully situated place we had a hard journey to Rambouillet, over a military road two thirds cobblestones and one third rough gravel and mud.

We were now within a short distance of Versailles and Paris, where our journey was to end. Reaching Versailles, the magnificent exterior of the great palace could not fail to impress us, but one at first feels out of place in the midst of so much cold, monumental grandeur, and our short trip through the galleries and gardens gave us all the impression that a great amount of money had been lavishly expended with questionable success. It is needless to say that many of the little village scenes through which we had passed were more picturesque and effective and could be more quickly grasped.

A quick afternoon ride from Versailles led us through the Bois de Boulogne, past the Arc de l' Etoile, down the crowded Champs-Elysées, to the little comfortable hotel in the Rue de Bac, and our Summer School of '96 was ended.

During our stay abroad much information was gained in regard to the European styles of architecture. In fact, so great an advance in the appreciation of good architecture was made, that all who took part in the tour look back upon it as completely enjoyable and profitable. At this distance, our days of monotonous riding and all our difficulties are forgotten.

THE VISCOSITY OF MERCURY VAPOR.

By A. A. NOYES, Ph.D., and H. M. GOODWIN, Ph.D.

Received October 6, 1896.

The uncertainty which attaches to the specific heat ratio of gases as a means of distinguishing between monatomic and polyatomic molecules has been recently made evident by the extended discussions of the significance of that property in connection with the atomic weights of argon and helium. It is, therefore, of great interest to investigate other properties which may be expected to be related to the atomicity of the molecule. Of such properties those dependent on the volume or cross-section of the molecules seem most promising. We have, therefore, undertaken the investigation of one of these, the viscosity or internal friction, in order to determine whether a marked difference in its value exists in the case of gases with monatomic and those with polyatomic molecules. To this end we have made comparative measurements of the viscosity of hydrogen, carbon dioxide, and mercury vapor at the boiling temperature of the last named substance. According to the Kinetic Theory of Gases the viscosity coefficient η has the theoretical significance expressed by the following equation :[1]

$$\eta = \frac{1}{\pi} N m L c$$

in which N is the number of molecules in the unit of volume, m the mass of a single molecule, L the mean free path, and c the mean velocity. Moreover the mean free path L is dependent solely on the number of molecules N and the mean cross section q of a single molecule, or of its sphere of action :[2]

$$L = \frac{1}{4\sqrt{2}\, N q}$$

[1] O. E. Meyer. Kinetische Theorie der Gase. 1st ed. pp. 130, 139.

[2] O. E. Meyer. Kinetische Theorie der Gase, pp. 206, 218. The symbol Q used by the author represents the total cross section of all the molecules in the unit of volume, and is, therefore, evidently equal to Nq.

whence it follows that

$$\eta = \frac{1}{4\pi\sqrt{2}} \frac{mc}{q}$$

or for any two different gases:

$$\eta_1 : \eta_2 :: \frac{m_1 c_1}{q_1} : \frac{m_2 c_2}{q_2}$$

But, since for any two gases at constant temperature:

$$m_1 {c_1}^2 = m_2 {c_2}^2$$

the above proportion may be simplified to the following equation:

$$\frac{q_1}{q_2} = \frac{\eta_2}{\eta_1} \sqrt{\frac{m_1}{m_2}} \qquad (1)$$

from which it is evident that the relative mean cross sections of the molecules of the two gases are readily calculated from their molecular weights and viscosity-coefficients. It was thought by us that monatomic molecules might prove to be much smaller than polyatomic ones, since it seems *a priori* not improbable that the spaces between the atoms of the latter are large in comparison with the dimensions of the atoms themselves. The experiments to be here described show, however, that no marked distinction exists between monatomic and polyatomic gases in this respect.

Experiments on the viscosity of mercury vapor, and especially on the effect of temperature upon it, have been made already by S. Koch,[1] who calculated that at 300° the volume of the mercury molecule is 4.4 as great as that of the hydrogen molecule. As this calculation was not based on direct comparative experiments made by passing the two gases through the same capillary, but was an indirect one involving the measurements of different experimenters and the dimensions of the capillaries used by them, it seemed desirable to subject the matter to further investigation in the direct manner indicated. Moreover, the author does not discuss the significance of his result in its bearing on the relative magnitude of atoms and molecules.

The method used by us in determining the relative viscosity consisted in measuring the quantities of the different gases which, under a constant difference of pressure, passed in a given time through the

[1] Wied. Ann. Phys. Chem. **19**, 857 (1883).

same capillary kept at a definite constant temperature. O. E. Meyer[2] has derived the following formula for calculating the viscosity coefficient η of a gas from its rate of flow through a capillary tube:

$$\eta = \frac{\pi}{16} \frac{R^4}{\lambda} \frac{(p_1^2 - p_2^2)\, t}{p_1 V_1} .$$

where λ is the length and R the radius of the tube, t the time, p_1 the pressure at which the gas enters, p_2 that at which it leaves the tube, and V_1 the volume of the transpired gas measured at the pressure p_1. In the case of comparative experiments made with the same capillary on two different gases, the following proportion holds true:

$$\eta_1 : \eta_2 :: \frac{(p_1^2 - p_2^2)_1\, t_1}{n_1} : \frac{(p_1^2 - p_2^2)_2\, t_2}{n_2} \qquad (2)$$

in which n_1, n_2, represent respectively the number of gram molecular weights of the two gases transpired (since n is proportional to the product $p\,V$).

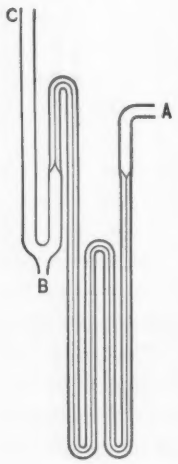


Fig. 1.

The apparatus and experimental method that we employed were necessarily quite different from the usual ones, and they will, therefore, be briefly described. The capillary used in the most complete series of experiments consisted of a glass tube about 74 cm. in length, and 0.34 mm. in internal diameter (determined by measuring the volume of a known length by means of mercury). A smaller capillary about 49 cm. in length and 0.22 mm. in diameter was used in a preliminary series. The capillary was bent in the manner shown in Figure 1, except that as actually constructed, it was made much more compact. To its ends were fused pieces of ordinary glass tube as shown in the figure; one of these was provided at the point A with a ground glass joint. The capillary was placed in a vertical position in a heavy steel cylinder (see Figure 2), 30 cm. high, 2.8 cm. internal diameter, having a small orifice at the side, through which the ground joint protruded for a distance of about one centimeter. The

[2] Pogg. Ann., 127, 269.

capillary was held in position in the orifice by packing with loose asbestos. Although the capillary was vertical, the influence of gravity was eliminated by reason of the fact that the ascending and descending parts were made equal in length. The top of the cylinder was closed by an iron plate screwed down with a nut N; the nut and the plate were perforated in the center, and into the latter was welded an open iron tube B projecting upwards, 25 cm. in length, and $1\frac{1}{2}$ cm. in diameter. The cylinder was covered, except on the bottom, with a jacket of asbestos about 5 cm. thick, and the projecting tube B, which was to serve as a condenser, was wound with spirals of copper wire to increase the

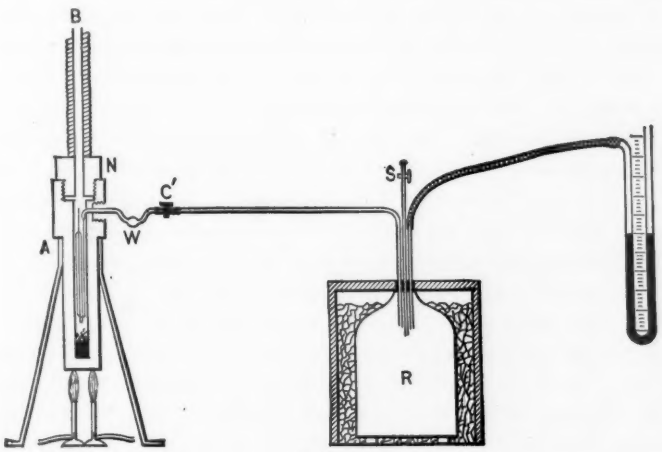


Fig. 2.

cooling surface. Pure mercury was placed in the cylinder and boiled vigorously by means of a number of lamps beneath. The capillary was thus kept at the boiling temperature of mercury under atmospheric pressure. No regard was paid to the variations of temperature arising from changes in barometric pressure, as their effect would evidently be entirely negligible.

Any desired difference of pressure at the two ends of the capillary was attained by inserting a tube in the ground joint and connecting it with a large air reservoir R which was itself connected through the cock S with a suction pump, and with an open mercury manometer M. The gas or vapor entered at the other end of the capillary, always un-

der atmospheric pressure. The whole apparatus in the form used for measuring the rate of transpiration of the mercury vapor is shown in Figure 2.

In making the experiments, the rate of flow of the mercury vapor was first determined in the following manner: While the cylinder was being heated, carbon dioxide was forced through the capillary to prevent the condensation in it of liquid mercury and the formation of its oxide. After the mercury was boiling actively, and its vapor entirely enveloped the capillary as shown by a mercurial thermometer inserted in the tube *B*, Figure 2, it was connected with the suction pump and mercury vapor drawn through for half an hour. The carefully ground end of a weighed bulb *W* was then inserted in the ground joint and its other end being connected by means of a clamped rubber tube *C*, with the air reservoir, in which the desired reduction of pressure had been produced. At a definite moment the clamp *C* was opened and the time noted. As the volume of the condensing bulb *W* was very small compared with the volume of the air reservoir, no sensible change in the pressure was thus produced. The mercury vapor was found to be completely condensed in *W* about two to three centimeters from the ground point. It was found that a slight and unavoidable leakage [1] through the ground joint occurred, and it was, therefore, necessary to readjust the pressure occasionally. It could easily be maintained constant to 0.2 or 0.3 mm. or even closer. After a sufficient time, usually sixty minutes, the clamp was closed, and at a noted instant the bulb removed and subsequently weighed. Check experiments were made in this way at each of two or three other different pressures.

The capillary was now removed from the cylinder, and the opening *B* (Figure 1) carefully closed by fusion. A glass tube, long enough to project beyond the upper end of *B* (Figure 2), was also fused onto the end *C*, and the capillary was then ready for the experiments with carbon dioxide and hydrogen. It was replaced in the cylinder as before, and the glass tube projecting through *B* connected through suitable wash-bottles with the gas generator. The carbon dioxide was made

[1] In the case of the mercury experiments, no error could arise from this source, as the leakage was inward. In the case of those with carbon dioxide and hydrogen, it was proved by blank experiments that the amounts of carbon dioxide and water which leaked in were less than 1 per cent. of the total weight.

in a Kipp generator by the action of dilute sulphuric acid on lumps of pure fused sodium carbonate, and was dried by passing through two Allihn gas wash-bottles containing strong sulphuric acid. The hydrogen was prepared from pure Bertha zinc and dilute sulphuric acid, was washed with caustic soda solution and dried by sulphuric acid as in the case of the carbon dioxide. In order to maintain the gas entering the capillary at atmospheric pressure, a T tube was inserted between the wash-bottles and the capillary, and its perpendicular arm was turned downward and caused to dip into sulphuric acid barely below its surface. The cock of the generator was opened sufficiently to cause the gas to bubble out steadily through the sulphuric acid.

The transpiration measurements were made as in the case of the mercury. The carbon dioxide, flowing through in a definite time, was determined by absorption in weighed tubes filled with lumps of soda lime. The hydrogen was burnt by passing it over hot copper oxide contained in hard glass tubes from which the air was previously displaced by carbon dioxide, and the water collected in weighed calcium chloride tubes.

The results are presented in the following table: In the first column is given the symbol of the substance; in the second, the atmospheric pressure p_1; in the third, the difference in pressure $(p_1 - p_2)$; in the fourth, the time t expressed in hours; in the fifth, the weight w in grams of the substance weighed; in the sixth, the mean weight transpired in one hour as computed from the separate check experiments, and in the last, the quotient obtained by dividing this weight by the molecular weight m of the substance, the time, and the pressure function $(p_1^2 - p_2^2)$[1]. (See expression (2) on page 48. As the headings indicate, the first of these two series of experiments was made with the smaller, and the second with the larger capillary. It will be seen that in the second series two sets of determinations are given for mercury vapor; the first of these was made before, and the second one after the experiments with carbon dioxide and hydrogen, and their agreement shows that the capillary had undergone no change by stoppage or otherwise, during the course of the experiments with it.

[1] In the calculation of this quantity the same mean value of p_1 was used in all the experiments of each series, namely, 760 for those with the smaller capillary, 765 for those with the larger.

SERIES I. (Small Capillary.)

	p_1	$p_1 - p_2$	t	w	$w : t$	$\frac{w \times 10^{10}}{tm(p_1^2 - p_2^2)}$
Hg . .	753	200	1½	0.738		
	753		1½	0.740		
	756		1½	0.745	0.494	93.6
	755	300	1	0.685		
	755		1	0.686	0.686	93.6
	754	400	1	0.834		
	754		1	0.831	0.833	92.9
CO_2 . .	752	200	1	0.237		
	752		1	0.239		
	752		1½	0.357	0.238	205
	759	300	1	0.329		
	759		1	0.327		
	766		1	0.324	0.327	203
	766	400	1	0.400		
	766		1	0.396		
	759		1	0.396	0.397	202

SERIES II. (Large Capillary.)

	p_1	$p_1 - p_2$	t	w	$w : t$	$\frac{w \times 10^{10}}{tm(p_1^2 - p_2^2)}$
Hg. . .	769	150	1	1.548		
	769		1	1.548	1.548	374
	769	300	1	2.763		
	769		1	2.764		
	769		1	2.739	2.755	373
CO_2 . .	756	150	1	0.704		
	765		1	0.706	0.705	774
	765	300	1	1.267		
	765		1	1.264	1.265	779
H_2. . .	766	150	1	0.557		
	766		1	0.557	0.557	1517
	766	300	1	1.009		
	766		1	1.006	1.008	1496
Hg. . .	766	300	1	2.728		
	766		1	2.746		
	764		1	2.743	2.739	371

Attention may be first called to the agreement of the values of the last column in the case of the transpiration of the same substance under different differences of pressure, thus proving that the effect of pressure is in close accordance with that required by the formula, and consequently that the capillaries are of sufficient length and small enough bore to give the true values of the viscosity coefficients.

Of the two series of experiments, the first one made with the smaller capillary is to be regarded as less reliable by reason of the fact that owing to an accident to the capillary check experiments with mercury vapor after completion of those with carbon dioxide could not be made as in the former case, in consequence of which it is not certain that a stoppage did not occur in the course of the series. While there was nothing to indicate that such was the case, yet on account of its extremely small bore it was much more liable to stoppages than the larger capillary. We consider the experiments with the latter to be certainly accurate within 2 per cent.

Nevertheless, the agreement between the results of the first and second series is perhaps as close as could be expected with capillaries so different from each other in character. The relative viscosity coefficients of the different gases were calculated from the values of the last column in the table by means of formula (2). The results are as follows:

First series,

$$\frac{\eta_{Hg}}{\eta_{CO_2}} = 2.17.$$

Second series,

$$\frac{\eta_{Hg}}{\eta_{CO_2}} = 2.08. \qquad \frac{\eta_{Hg}}{\eta_{H_2}} = 4.04. \qquad \frac{\eta_{CO_2}}{\eta_{H_2}} = 1.94.$$

The relative values for mercury and carbon dioxide agree within about 4 per cent. That of the second series is, however, more reliable, for the reason above stated, and will be used in the subsequent calculations. It may be noted that the value of the ratio $\eta_{CO_2} : \eta_{H_2}$ at ordinary temperature is 1.72,[1] somewhat smaller than that found by us at 357°, a result which is in accordance with the greater temperature coefficient of carbon dioxide established by several investigators.

[1] O. E. Meyer. Kinetische Theorie der Gase, 142.

The corresponding values of the relative mean cross-sections as calculated by formula (1) are:

$$\frac{q_{Hg}}{q_{CO_2}} = 1.02. \qquad \frac{q_{Hg}}{q_{H_2}} = 2.48.$$

That is to say, the average cross-section of the mercury molecule or atom is very nearly the same as that of the carbon dioxide molecule, and is about $2\frac{1}{2}$ times as large as that of the hydrogen molecule. This last result does not differ very greatly from that (2.68) corresponding to the relative molecular volumes of mercury and hydrogen as calculated for 300° by Koch.

These results indicate that *atoms and molecules are of the same order of magnitude* and that the spaces between the atoms within the molecule, if any exist, are not large in comparison with those occupied by the atoms themselves. And consequently the viscosity of gases, or any other property which like it is dependent only on the size or form of the molecules, is not adapted for distinguishing between monatomic and polyatomic molecules.

In considering the significance of the above values of the cross-section, the different masses of the various molecules, to be sure, ought not to be entirely disregarded. The mercury and carbon dioxide molecules have, as we have seen, the same cross-section, and, therefore, assuming both to be of the same general form, they occupy the same volume. The mass of the former is, however, 4.55 times as great as that of the latter. The density of the mercury molecule is consequently greater in this same proportion. But this difference is not marked enough to make it necessary to attribute it to free spaces within the carbon dioxide molecule. For it is not improbable that the inherent density of massive atoms, like those of mercury, may be considerably greater than that of light atoms, such as those of carbon and oxygen.

In closing, we desire to point out that the principle here established that atoms and molecules are of the same order of magnitude, and that no considerable free interatomic spaces exist within the molecule, is in accordance with the remarkable fact that the molecular cross-section of most comparatively simple molecules is approximately an additive property calculable from certain constant values of the atomic cross-section.[1] This fact would be unintelligible, were the principle

[1] See O. E. Meyer. Kinetische Theorie der Gase, 209.

not correct; for if considerable spaces existed between the atoms, it is not to be supposed that those spaces would be the same in entirely dissimilar molecules — that, for example, the space between the hydrogen and chlorine atoms in hydrochloric acid would have any relation to the space between the atoms in the elementary gases hydrogen and chlorine.

ROGERS LABORATORY OF PHYSICS.
September, 1896.

THE SCIENTIFIC WORK OF THE BOSTON PARTY ON THE SIXTH PEARY EXPEDITION TO GREENLAND.

I.

Introductory Note.

On the 29th of April, 1896, the undersigned received a letter from Lieutenant Robert E. Peary, Civil Engineer U. S. N., inviting him to organize a small party to carry on some line of scientific research in Danish Greenland, this party to be quite independent in its organization and equipment from the main body of the expedition, but to be transported to and from its destination by Lieutenant Peary's steamer. A similar proposition was made to Professor Ralph S. Tarr, of Cornell University. These two separate parties of six men each were to be landed with boats and camp equipments at different points on the west coast of Danish Greenland, there to remain and to carry on their investigations until the return of Lieutenant Peary's steamer in the latter part of the season, when they were to be taken on board and brought back to the port of sailing. This plan was a variation from former expeditions, and was designed to enable the members of these parties to prosecute their studies uninterruptedly for five or six weeks at localities affording the best opportunities for their chosen lines of work.

Both parties were organized and equipped, and they sailed with Lieutenant Peary from Sydney, Cape Breton, on the steamer Hope, July 16, 1896. Lieutenant Peary had obtained permission from the Danish home government for the landing of these parties on the Greenland coast. The entire plan as proposed was carried out almost without a single deviation. Each party was landed and called for on scheduled time, and too much praise cannot be given to Lieutenant Peary and Captain Bartlett, of the steamer Hope, for the excellent arrangements made for the comfort and safety of their passengers.

Through the kindness of the Secretary of the Treasury and of the Superintendent of the United States Coast and Geodetic Survey, the Boston party was fortunate in securing the detail of Assistant G. R. Putnam with full instrumental equipment for making pendulum and magnetic observations. The other members of the party were college professors and students. The expenses of the party were mainly borne by the members themselves. The undersigned, however, wishes to express his sincere gratitude to Mrs. Francis H. Williams, Mrs. John C. Phillips, Mr. George Wigglesworth, and others, for their aid and financial assistance, without which the work of the party would have been seriously hampered. To Mr. A. M. Ritchie, of Brookline, the party is indebted for the gift of a complete thermophone outfit for the determination of air, ice, and water temperatures, and to the Institute of Technology for the loan of scientific instruments.

The Boston party wishes to acknowledge with hearty appreciation the courtesy and generous assistance extended to them throughout their work by the Danish officials, and especial thanks are due to Inspector Andersen, of Godhavn, and to Governor Knuhtsen, of Umanak.

The account of the scientific work accomplished will be given in the following reports by the members of the expedition.

Report A. Magnetic and Pendulum Observations, by Mr. G. R. Putnam, Assistant United States Coast and Geodetic Survey.

*Report B.** Observations of Glacial Phenomena, by Assistant Professor G. H. Barton, Massachusetts Institute of Technology.

*Report C.** Measurements of the Motion of the Great Karajak Glacier, by Professor A. E. Burton, Massachusetts Institute of Technology.

*Report D.** Studies of the Eskimos of Baffin's Land and Umanak Fjord, Their Costumes and Habitations, by Mr. Russell W. Porter, a student, Massachusetts Institute of Technology.

Although the two remaining members of the expedition, Mr. John C. Phillips, a student of Harvard University, and Mr. A. M. Dodge, a student of Harvard Medical School, do not submit written reports of their work, it should be said that much of the success of the plans of this expedition is due to their hearty coöperation in the work, and to their practical knowledge of camp life. Messrs. Porter, Phillips, and Dodge, by their skill in the use of the camera, enabled the party to obtain a most excellent photographic record of the expedition.

A collection of furs, native costumes, kayaks and implements of the chase was made, and much of it has already been presented to various museums and public collections.

ALFRED E. BURTON, S. B.,

Professor of Topographical Engineering, Massachusetts Institute of Technology,
In charge of the Boston party.

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*Owing to lack of space, reports *B*, *C* and *D* will be published in the next number of the TECHNOLOGY QUARTERLY.

Report A. Magnetic and Pendulum Observations in Connection with the Greenland Expedition of 1896, Under Charge of Professor A. E. Burton.[1]

By G. R. PUTNAM, M.S.,
Assistant U. S. Coast and Geodetic Survey.

Received January 18, 1897.

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[1] Published by permission of the Superintendent of the United States Coast and Geodetic Survey.

Part I. Introduction.

Section 1. *Scope and Object of Work.* — Among the objects of research included in the plan for the expedition to the west coast of Greenland organized by Professor A. E. Burton in the summer of 1896, were magnetic and pendulum observations, and the writer was invited by Professor Burton to undertake this part of the work. On the recommendation of the Superintendent of the United States Coast and Geodetic Survey, permission was granted by the Secretary of the Treasury for the writer to accompany the expedition, and to take with him the necessary instrumental outfit belonging to the Survey, on the condition that the Survey should bear no part of the expense. The party was to be transported to and from its destination by Lieutenant R. E. Peary, United States Navy, the well known Arctic explorer, who combined the transportation of several such scientific parties with the other objects he had in view in planning this northern expedition. As Lieutenant Peary proposed to make a number of intermediate stops both going and returning, it was the plan of the writer to make observations at all such places as time and circumstances would permit, and thus accumulate as much data as possible in regard to these branches of terrestrial physics, in regions not frequently visited. In the recently published report[1] of Professor Helmert to the International Geodetic Association on gravity determinations made in various parts of the world, no observations are shown in the region covered by this voyage, so that pendulum observations here will help to fill a gap in the investigation of the variations of the force of gravity over the earth's surface, which is among the lines of research undertaken by the various countries represented in that association. One of the objects of these investigations is the study of the figure of the earth, as to which evidence is furnished by the variations in the force of gravity from the equator to the poles; and the fact that comparatively few such observations have been made in the polar regions where they have great weight in this problem, renders additional data there of especial importance. The study of the local variations of gravity is also of much interest, furnishing evidence of the differences of

[1] "Bericht über die relativen Messungen der Schwerkraft mit Pendelapparaten," by Professor Helmert, in "Verhandlungen der elften allgemeinen Conferenz der Internationalen Erdmessung," at Berlin (1895). See map No. 7.

density near the earth's surface, and affording one of the few experimental means of investigating that important problem of terrestrial physics, the condition of the earth's so-called crust.

Magnetic observations have been made from time to time by various expeditions to these regions. The repetition of such observations at identical stations after suitable intervals of time, has long been considered an object of prime importance in the study of terrestrial magnetism, as by this means only can the changes constantly in progress in all the magnetic elements be intelligently studied. The direct practical bearing of these observations in connection with navigation and surveying, is the knowledge they afford of the variation of the compass from true north, and the possibility of predicting what the variation will be for at least a few years in advance. It was fortunate that at a number of places it was possible to reoccupy the stations of earlier magnetic observers, in two cases the identical points being found. The advantage of this, of course, is that the local variation which exists in the vicinity of many points is eliminated in deducing the rate of change of the magnetic elements from successive observations.

On account of the ready portability of the magnetic instruments it was possible to take advantage of nearly all the stops of the ship to make magnetic observations. The pendulum apparatus, however, being much more elaborate, and requiring the obtaining of star observations for time on at least two nights, could only be set up where the longer stops were made, and complete observations were obtained only at the points of starting and destination, with partial observations at two intermediate places. Because of the diversified interests comprised in the various expeditions on the ship, the short time available, and the exigencies of Arctic voyaging, the stops could not be arranged either as to time or place, to especially accommodate the magnetic and pendulum observations, but the convenience of this work was considered by Lieutenant Peary in arranging the plans, and the work promoted in every way practicable.

The present report on this work includes many details and illustrative examples of observations, and historical references to former work, which are embodied here with the purpose of giving a more complete idea of the methods and objects, as well as of the actual results obtained; to do this it is evidently necessary to repeat some data that have been published in earlier reports.

SECTION 2. *Narrative of the Expedition as Relating to these Observations.* — The starting point of the steamship "Hope," which was to carry the parties north, was Sydney, Cape Breton. In order to personally see to the transfers *en route* of the valuable instrumental outfit I left Boston by boat on July 4, 1896, reaching Halifax, Nova Scotia, on July 6. Here by permission of the British officers in charge, I made magnetic observations at the Naval Dock Yard, which is one of the most valuable secular variation stations in North America, the series of magnetic declination observations in this vicinity extending back nearly three centuries. Leaving Halifax July 8, on the steamer "Harlow," and passing through the remarkable Bras D'Or lakes, Sydney was reached on July 10. Magnetic, pendulum, and astronomical instruments were set up the same day, and work commenced that evening. Complete observations were obtained at this point, the instruments being located in the yard and basement of the Sydney Hotel, through the courtesy of Mr. J. P. Fairbanks. All the parties and outfit were embarked at this point on board the "Hope," a stanch Newfoundland sealing steamer of 322 tons, full rigged and especially adapted for work in the Arctic regions, and under the command of Captain John Bartlett, an experienced Arctic voyager. Professor Burton's party comprised, besides the writer, the following persons: Professor A. E. Burton, Massachusetts Institute of Technology, in charge, Professor G. H. Barton, geologist, Mr. R. W. Porter, artist, both also of the Institute, Mr. A. M. Dodge, Harvard Medical School, and Mr. J. C. Phillips, Lawrence Scientific School. The writer is indebted to these gentlemen for much assistance in preparing stations and for helping in other ways. Professor Burton, besides making the topographical sketches at several of the points, constantly facilitated and encouraged the work.

The "Hope" sailed from Sydney on July 16, our course being across the Gulf of St. Lawrence, through the Straits of Belle Isle, and along the Labrador coast. On July 20, a few hours' stop was made at Turnavik, where magnetic observations were made over the exact spot occupied by Lieutenant Very, United States Navy, fifteen years previously. For most of the distance along the Labrador coast floe ice was encountered, which became so heavy in the vicinity of Cape Chudleigh as to seriously impede the progress of the ship. Hudson Strait was entered on July 23, and found comparatively free from ice. Our party was landed at Ashe Inlet, Big Island, on July 25, and the various instruments were set up in the vicinity of the partially destroyed house

marking the site of the Canadian meteorological station established ten years ago, in connection with the Hudson Bay expedition under Lieutenant A. R. Gordon, Royal Navy. Magnetic, pendulum, and one night's time observations were made here, but the second night's time observations were prevented by an easterly gale and rain which also interfered with the magnetic work. The "Hope," which had gone to the mainland, called for our party on July 27, and no further time was available at this point. We passed out of Hudson Strait on July 29, and were prevented from entering Cumberland Sound, as planned, by heavy ice which apparently blocked the whole width of the entrance. On July 31 the course was changed for Greenland, the coast of which was sighted on the evening of August 1. Steaming northward along that coast we entered the harbor of Godhavn on the evening of August 2, and were cordially welcomed by the Danish officials. By permission of Mr. Andersen, the Inspector of North Greenland, I made magnetic observations the next morning in a location between the Inspector's and Governor's houses, and probably very close to the former stations, which are referred to as being in the Inspector's garden, or near the flagpole. Later the magnetometer was taken across the harbor to the west side of Watson's Bay, and a few observations made there. This is thought to be in the vicinity of the "Discovery's" station of 1875. Leaving Godhavn on the afternoon of August 3, the "Hope" steamed through the remarkable passage inside of Disco Island, known as the "Vaigat." Entering Umanak Fjord on August 4, our destination at Umanak settlement on the little island of the same name was reached on August 5, and our party was disembarked, and the "Hope" proceeded on her more northern voyage. By the courtesy of Mr. Hjalmar Knuhtsen, the Governor of the Danish district of Umanak, an unused house known as the "Gamle Præstebolig" (old parsonage) was placed at our disposal, for storage and living purposes. Throughout our stay here the Danish officials were most courteous and hospitable, and facilitated our work in every way. The pendulum apparatus was set up in a corner of this house, and the meridian telescope and magnetic instruments in tents close by. By August 21 the observations at this point had been completed, and duplicate records prepared, which as a precaution were sent to America by the last Danish ship of the season, the "Peru" of the Royal Greenland Trade. After this the writer accompanied one of the several expeditions which were made by the party to the glaciers and the edge

of the inland ice, at the heads of the fjords. Because of the limited transportation facilities available, it was considered inexpedient to attempt to include pendulum or magnetic observations in the plan of these exploring trips, which were made in small boats. The party returned to Umanak on September 8, and on the following day the "Hope" arrived on her homeward journey, and all were reëmbarked. The same general course was followed on the return trip, omitting the voyage into Hudson Strait. The afternoon of September 11 was spent at Godhavn, and magnetic observations were again made at the same point in the village. A northerly gale was encountered that night, and on the 12th, in crossing Davis Strait. On the evening of the 13th the "Hope" ran into floe ice above Cape Mercy, which proved so heavy that practically no progress was made except the drifting with the floe until the 16th, when, the pack loosening, the ship was worked out and steamed into Cumberland Sound, which was found quite free of ice. On September 17 we reached the whaling station at Umanaktuak, or Blacklead Island, in the midst of a gale and snowstorm, so that difficulty was encountered in procuring an Eskimo pilot from shore. We then proceeded to Niantilik, or Winter Harbor, where the ship remained at anchor for about thirty hours. The magnetic, pendulum, and astronomical apparatus were set up on a low promontory on a small island just west of the anchorage. Magnetic and pendulum observations were made, but no star observations for time could be obtained because of a snowstorm, and the shortness of the stay. This point and Ashe Inlet were the nearest of this series of stations to the magnetic north pole, distant approximately 850 miles (1,370 kilometers). Leaving Blacklead on the morning of the 19th, a clear and favorable passage was had across to and along the Labrador coast, and again through the Straits of Belle Isle to Sydney, which was reached on September 26, after an absence of seventy-two days and a voyage of about 5,000 miles (8,000 kilometers). A few additional observations were made this day at Sydney, at Lieutenant Very's station of 1881, in the rear of the English Church. The instruments were then shipped to Washington, where the periods of the pendulums were carefully determined, October 15 to 17. They had been determined at Washington just previous to starting on this expedition, on June 22 to 24. The mean period of the three pendulums in October differed only .0000001 of a second from that determined in June, a very satisfactory test of the constancy of the pendulums and their

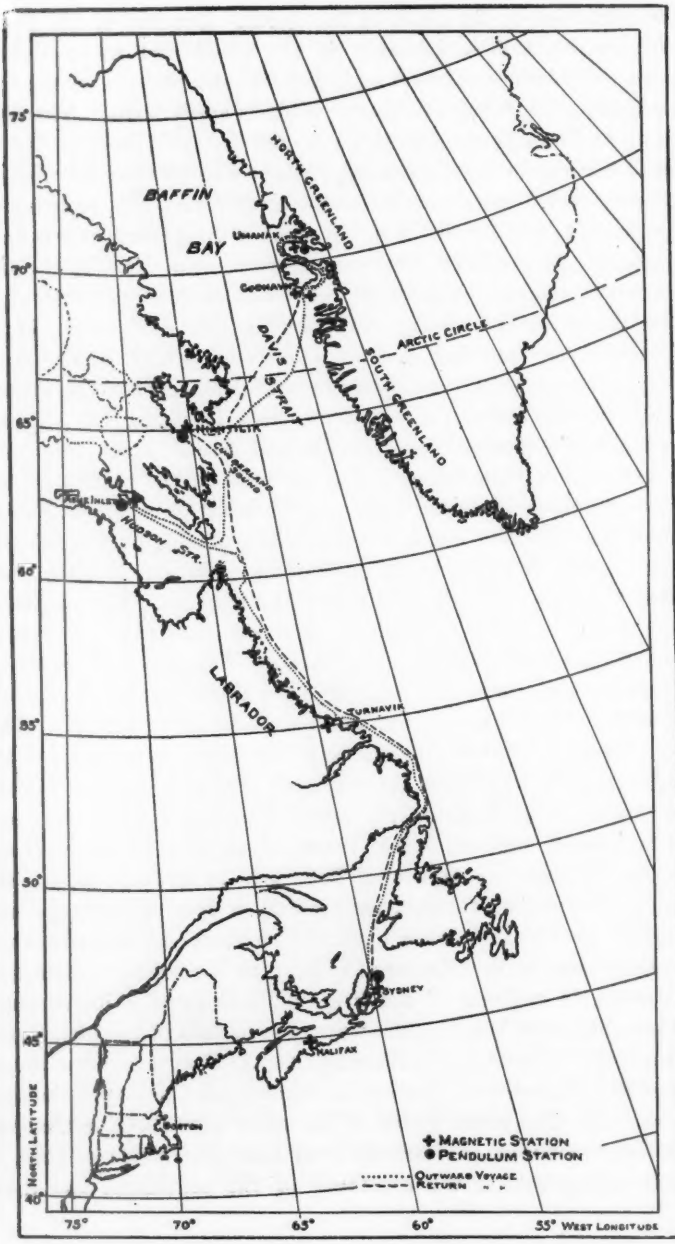
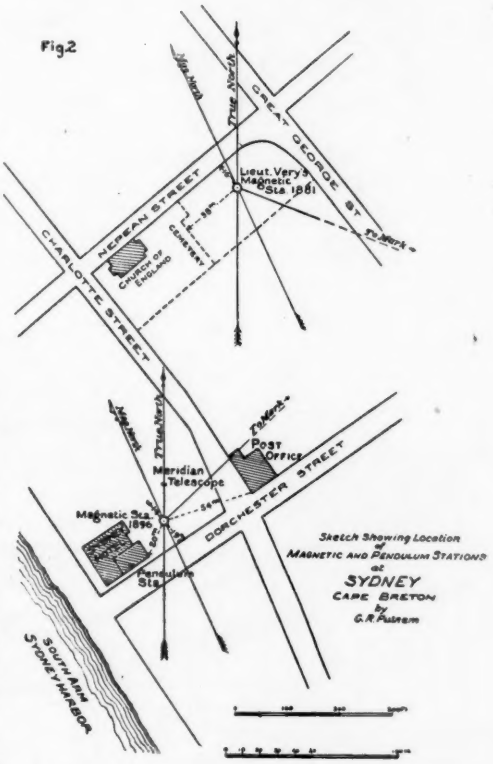


FIG. 1. SKETCH SHOWING GENERAL ROUTE OF THE EXPEDITION AND LOCATION OF MAGNETIC AND PENDULUM STATIONS.

freedom from injury on this journey. In this brief outline of the history of this expedition, only such details are referred to as affected these particular lines of work.

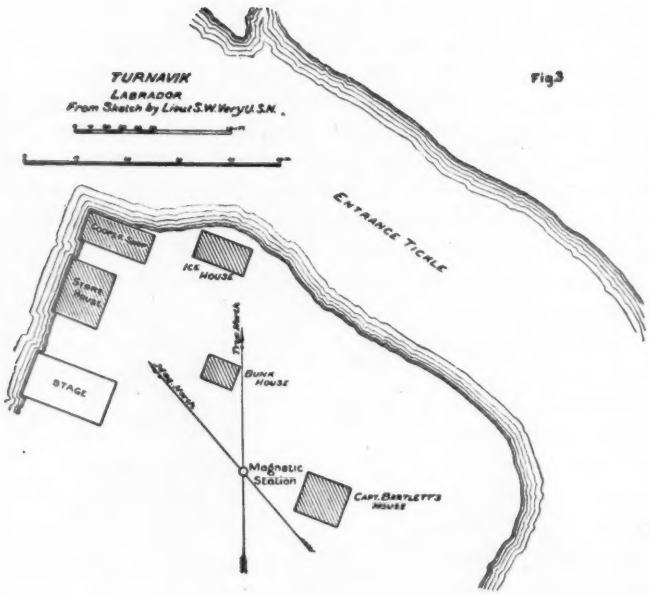
SECTION 3. *Description of Stations.* — There were in all eleven magnetic stations, in seven distinct localities. There were five pendulum stations (including the base station at Washington), at two of which the observations were incomplete. The route of the expedition and the points of observation are shown on the accompanying map, Figure 1, and the local positions of the various points on the separate sketches Figures 2 to 8. For further identification, the following brief description of the various points is added:



Washington, D. C. Pendulum station, in pendulum room in southwest corner of basement, Coast and Geodetic Survey Office on Capitol Hill.

Sydney, Cape Breton, Nova Scotia. Pendulum apparatus in front part of basement of Sydney Hotel. Magnetometer (station 1896) in open lot belonging to Sydney Hotel, and between it and Post Office.

Sydney, Cape Breton, Nova Scotia. Magnetic station of 1881, about 188 meters north, and 43 meters east of preceding. This station was occupied by Lieutenant S. W. Very, United States Navy, in 1881, and the wooden post left by him was found. It is in the rear of the Church of England, Figure 2.


TURNAVIK
LABRADOR
From Sketch by Lieut. S.W. Very U.S.N.
Fig.3
ENTRANCE TICKLE
ICE HOUSE
STORE HOUSE
STAGE
BUNK HOUSE
Magnetic Station
CAPT. BARTLETT'S HOUSE

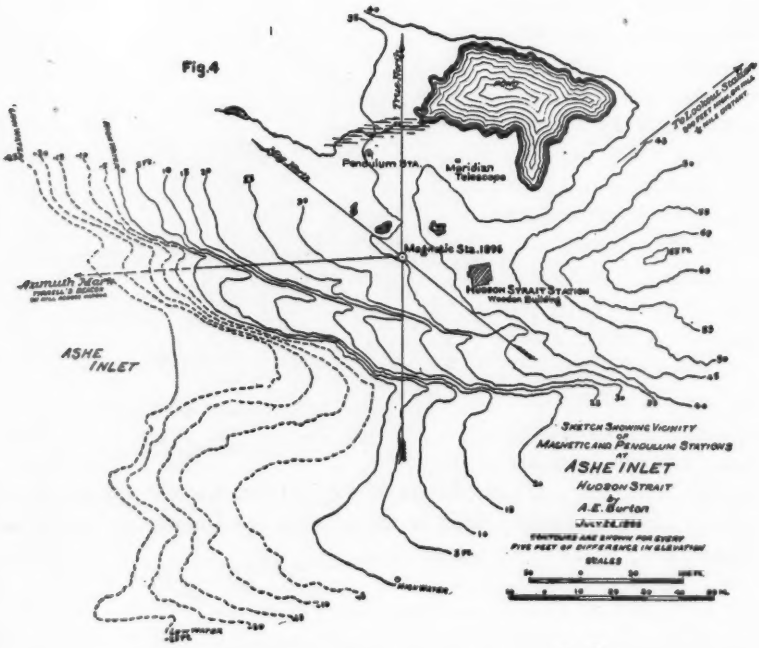


Fig.4
Pendulum Sta.
Meridian Telescope
Magnetic Sta. 1906
HUDSON STRAIT STATION
Wooden Building
Azimuth Mark
ASHE INLET
SKETCH SHOWING VICINITY OF MAGNETIC AND PENDULUM STATIONS AT
ASHE INLET
HUDSON STRAIT
BY
A.E. Burton
HIGH WATER

Turnavik, Labrador. Magnetic observations were made at the identical point occupied by Lieutenant Very, in 1881, on West Turnavik Island, in the midst of the small fishing settlement under charge of William Bartlett. This station is marked by a deep drill hole in the bare rock about half way between Bartlett's house and the house in which his men live, Figure 3.

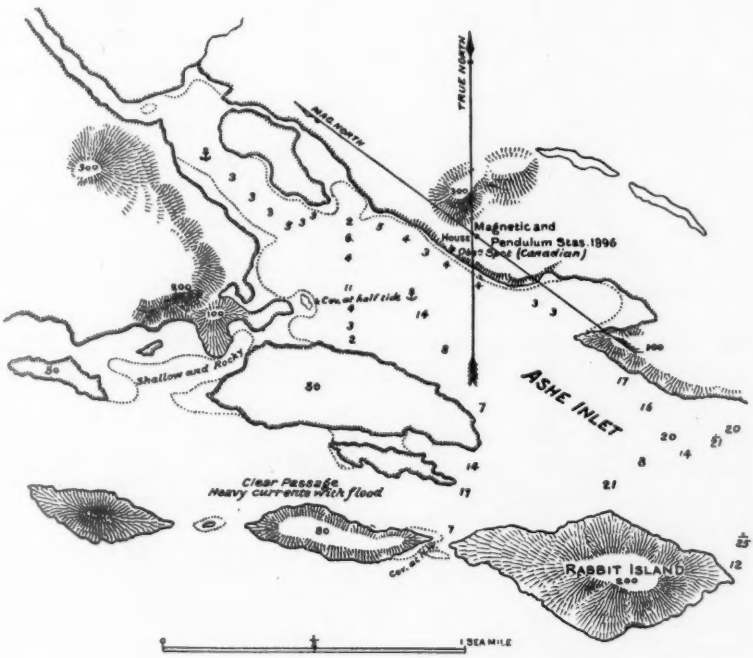
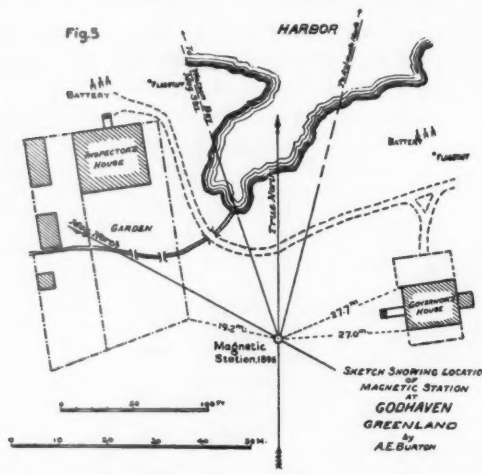


FIG. 4A. SKETCH OF ASHE INLET, HUDSON STRAIT.

From Admiralty Chart No. 1221. (1888.) *Soundings in fathoms, heights in feet.*
Observation Spot: Lat., 62° 32′ 44″ N.; Long., 70° 34′ 50″ W.

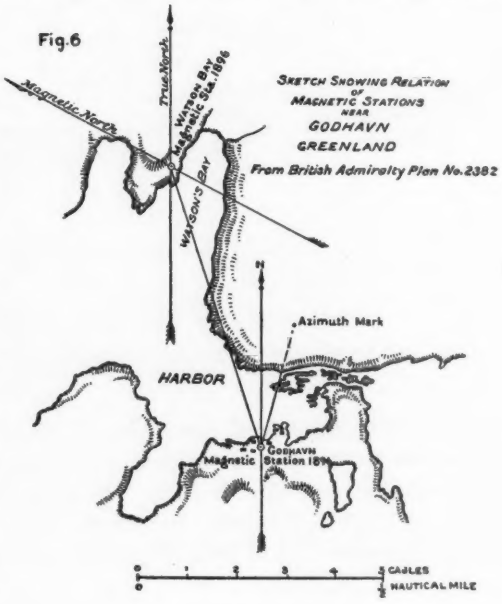
Ashe Inlet, Big Island, north side of Hudson Strait. Pendulum apparatus in low stone and turf hut northwest of Hudson Bay Expedition house on east side of Inlet. Magnetometer 23 meters west, and 5 meters north of house. Position of latter marked by drill hole 2 cm. in diameter in bed rock, Figures 4 and 4*a*.

Godhavn, Disco Island, Greenland. Magnetometer was located between the Inspector's and the Governor's houses, on slope of rocky ledge. It was quite near the flagstaff and garden probably referred to in description of previous stations. Position marked by a hole 2 cm. in diameter drilled in bed rock, Figure 5.



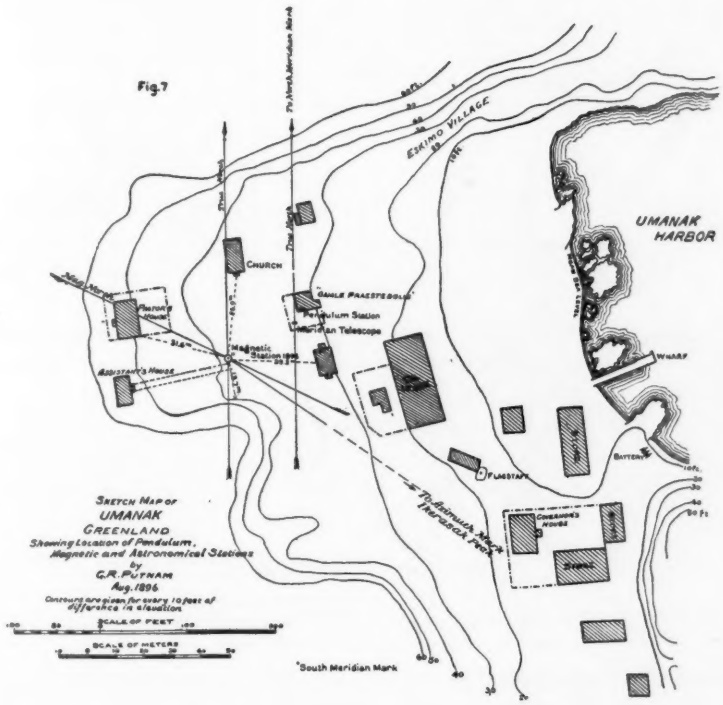
Watson's Bay, Godhavn Harbor, Greenland. This magnetic station was located across the harbor from Godhavn, on a slight promontory on west side of Watson's Bay as shown on Admiralty plan No. 2,382. Position marked by a hole 2 cm. in diameter drilled in bed rock, Figure 6.

Umanak, Greenland. At Umanak village on the small island and in the district of the same name. Pendulum apparatus on ground floor of building known as "Gamle Præstebolig." Magnetometer in open space south of church. Position marked by hole 2 cm. in diameter drilled in outcropping ledge of rock. The north and south meridian stations at Umanak were on the cliffs



in the meridian of the meridian telescope, 194 meters and 105 meters, respectively, north and south of the principal magnetic station, and were each similarly marked by drill holes in the rock, Figure 7. (For general vicinity see Admiralty chart No. 276).

Niantilik, Cumberland Sound. On a small island on the southwest side of Cumberland Sound, and lying just west of the anchorage known as Niantilik or Winter Harbor, and about eight kilometers



(five miles) south of the whaling station and Eskimo settlement at Umanaktuak or Blacklead. Pendulum apparatus was located in a tent on a low rocky point projecting from near the center of the southeast side of the island, and nearly south of the little sailors' cemetery by which the island may be identified. Magnetometer about 22 meters southeast of pendulum station. Latter point marked by hole 2 cm. in diameter drilled in gneiss rock, Figure 8. (For general vicinity

see map by Dr. Franz Boas, in Petermann's Mitteilungen, Vol. XVII, No. 80, 1885, Figure 8*a*.)

Section 4. *Geographical Positions and Elevations.* — The adopted values for the latitude, longitude, and elevation of the stations are given in the final tables of results (E and K). Except for Niantilik and Umanak, the latitudes are taken from the best available sources, such as records of previous observations, or from charts. At Niantilik, the latitude is from an adjustment of morning and afternoon sun

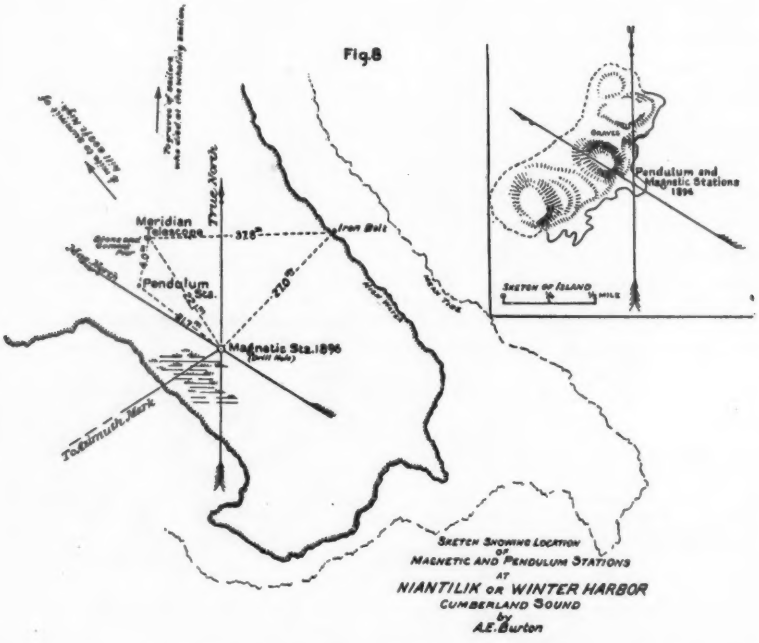


Fig. 8
Meridian Telescope
Pendulum Sta.
Magnetic Sta. 1896
Iron Bolt
True North
Talcumuth Mark
Pendulum and Magnetic Stations 1896
Sketch of Island
Sketch Showing Location of Magnetic and Pendulum Stations at Niantilik or Winter Harbor Cumberland Sound by A.E. Burton

observations for azimuth, checked by a rough sun observation at noon. At Umanak, observations of four pairs of stars on two nights were made with Meridian Telescope No. 13, using Talcott's method. The details of this determination are given in Section 17.

The longitudes of all the intermediate stations have been computed from the three chronometers, Numbers 1,823, 1,842, and 177, which were carried on the expedition, and are based on Sydney, Cape Breton, as a starting point, and Washington, D. C., as an ending point. The stationary rates were determined at Sydney, Umanak and Wash-

ington, and the traveling rates computed for the balance of the time. The local time for comparison with the chronometers was obtained at Ashe Inlet and Umanak, from star observations with the meridian telescope, and at the other points from the sun observations made with the theodolite magnetometer. The longitude results cannot be considered as very reliable for several reasons; the longitude of Sydney is uncertain, probably by a second of time; the chronometers were

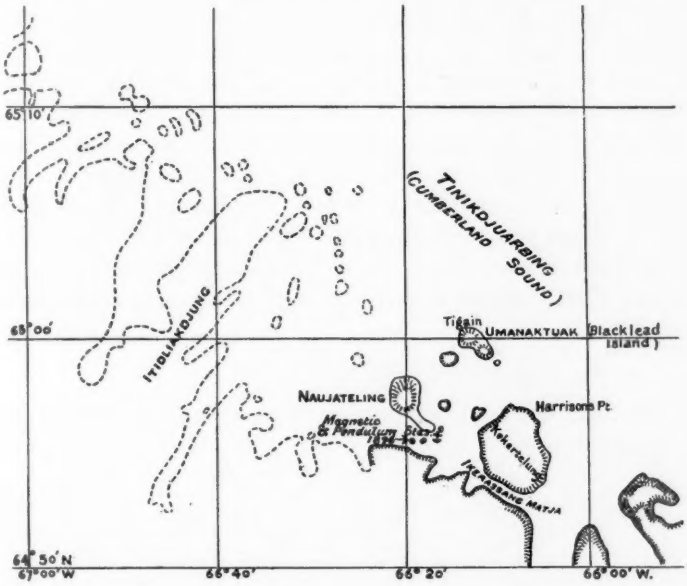


FIG. 8A. SKETCH OF A PORTION OF CUMBERLAND SOUND, SHOWING VICINITY OF MAGNETIC AND PENDULUM STATIONS OF 1896.

From map by DR. FRANZ BOAS, *Petermann's Mitteilungen*, Vol. 17, *Ergänzungsheft* No. 80, 1885.

subjected to a considerable variety of temperature and other conditions, including the jarring effect when pushing through the ice during many days; there was a long railroad journey from Sydney to Washington before they were last rated; and the magnetometer theodolite time determinations may be uncertain by several seconds. Nevertheless, the results by the three chronometers are fairly accordant, and agree well with previous values except for the two Greenland stations. The following table (A) gives the results by the three chronometers,

and a comparison with previous values. Because of its unsatisfactory performance, a weight of only one third is given to the results by chronometer 177. It will be noted that the discordances at the two Greenland stations between different authorities are considerable. At these two, the values determined in 1896 have been adopted, while at the other points the means of the present and earlier results have been used. In Section 18 is given as an example the computation of the longitudes by one of the chronometers.

The elevations of the pendulum stations were determined by hand level, using a Casella pocket alt-azimuth instrument. This instrument was found very convenient for the approximate leveling which fully answers the requirements of this work. Using as a base the height of the eye above the ground, picking up some natural object in the same horizontal plane, and following up grade in this manner, the difference in elevation to the nearest foot of points not distant may be obtained by one person almost as fast as he can walk between them. The mean sea level to which the elevations are referred was obtained by rough tidal observations, the mean of succeeding high and low waters being taken.

TABLE A.

SUMMARY OF RESULTS FOR LONGITUDE AND COMPARISON WITH PREVIOUS VALUES.

Station.	Reference point.	Longitude West of Greenwich.				Previous values of longitude.†
		Chronometer.				
		1823. Weight 3.	1842. Weight 3.	177. Weight 1.	Weighted mean.	
		h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.
Turnavik, Labrador	Magnetic station.	3 57 22.2	3 57 20.6	3 57 24.5	3 57 21.8	3 57 20.4 (1)
Ashe Inlet, Hudson Strait . .	Meridian telescope.	4 42 22.5	4 42 24.0	4 42 26.3	4 42 23.7	4 42 18.6 (2)
Godhavn, Greenland	Magnetic station.	3 34 04.8	3 34 05.2	3 34 03.0	3 34 04.7	3 33 36.5 (3) 3 34 48.0 (4)
Umanak, Greenland	Meridian telescope.	3 28 34.0	3 28 32.8	3 28 33.2	3 28 33.4	3 27 55.8 (5) 3 29 00.0 (6)
Niantilik, Cumberland Sound.	Magnetic station.	4 25 17.6	4 25 22.2	4 25 13.3	4 25 19.0	4 25 17.6 (7)
Sydney, Cape Breton.* . . .	Magnetic station, 1881.	4 00 42.8	4 00 45.8	4 00 28.8	4 00 42.1	4 00 46.9 (8)

* Sydney is included here only as a check. These longitudes are based on Sydney as a starting point, and Washington as an ending point.

† References for the previous values given.

Numbers 1, 2, 4, and 6, from British charts and plans.

Number 3. Bowditch, Practical Navigator.

Number 5. Meddelelser om Grönland, 4th part.

Number 7. Dr. Franz Boas' map.

Number 8. U. S. Hydrographic office chart.

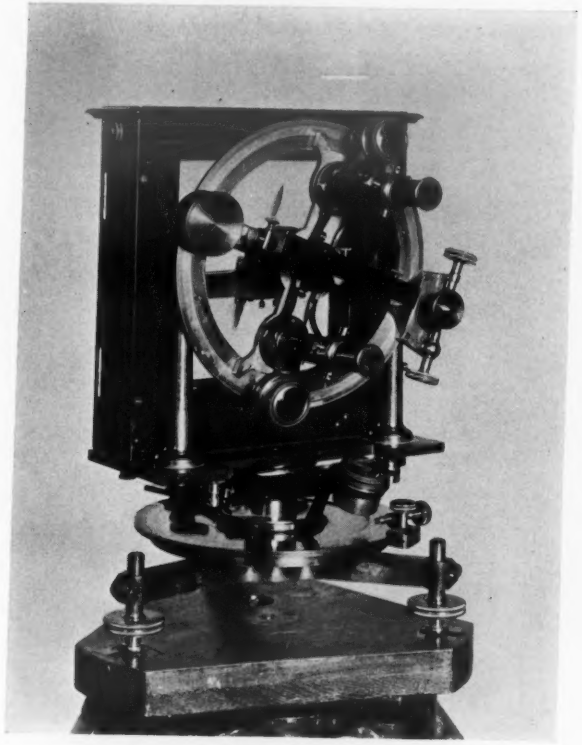


FIG. 9. DIP CIRCLE.

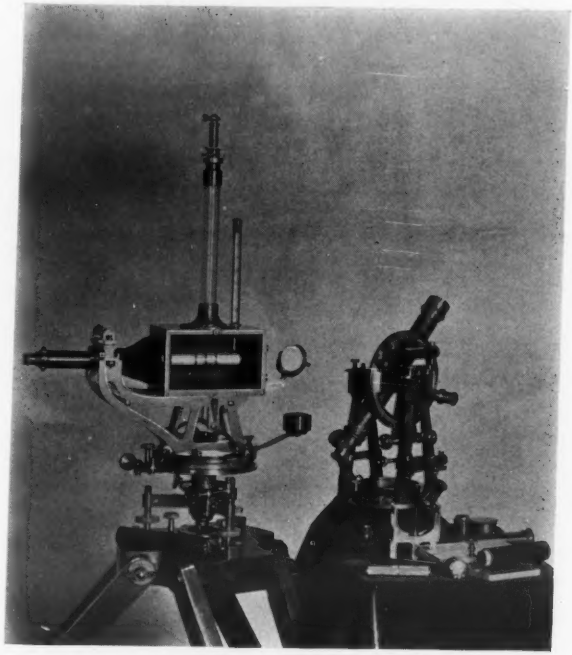


FIG. 10. MAGNETOMETER AND THEODOLITE.

Part II. Magnetic Observations.

Section 5. *Magnetic Instruments and Constants.* — A portable magnetic outfit was used, consisting of dip circle and magnetometer belonging to the Coast and Geodetic Survey. The dip circle (No. 4,655 by Casella) was of the ordinary Kew pattern, suited for work in high latitudes, with the supports for the needle horizontal, so as to permit of reading dips near 90°. It is shown in Figure 9. Its dimensions were horizontal circle 12.2 cm., vertical circle 14.4 cm. The magnetometer (No. 19) was one of the new instruments constructed at the Coast and Geodetic Survey Office in 1893, and is shown in Figure 10. It is of the general form long used in this country, and differing somewhat from the Kew magnetometer. It is a combination magnetometer and theodolite; the magnet box and attached small theodolite may be quickly removed from the base and horizontal circle, and replaced by the theodolite for determining the azimuth from the sun or otherwise. These new instruments have a horizontal circle of 11.2 cm. diameter, and vertical circle 9.8 cm., and have several improvements in detail greatly increasing the convenience of their use. The magnet is octagonal in shape, and is held in a similarly shaped stirrup, thus facilitating its reversal to obtain the axis. The suspension fibers (usually two fine silk fibers) hang from the adjustable torsion head at the top of the glass tube above the magnet box, and are attached to an arm extending upward from the stirrup. By this method the point of suspension is so high above the center of gravity of the magnet that the latter is little affected by dip, and will hang sensibly horizontal in ordinary latitudes. The principal magnet (19L) is a hollow steel bar about 7.4 cm. in length, and 1.1 cm. between opposite faces. It has a graduated scale in one end, and in the other a lens of such shape as to bring the scale into focus in the small observing telescope when the latter has the proper focus for a distant mark. This telescope is mounted eccentrically on the same support as the magnet box, and is provided with collimation and wye adjustments. The terrestrial reference mark may be observed with this telescope directly through the box, by lowering the magnet out of the way, turning aside the glass window at the further end of the box and lowering the light reflector outside. The hood between the end of the telescope and the magnet box enables the latter to be entirely closed against air currents when the magnet is being observed, and at

the same time renders it possible to observe both magnet and mark without looking through glass windows of any sort. For removing the torsion of the suspension fiber, a brass bar of the same weight as the magnet is provided. To support the magnet when it is used as a deflector, there are arms (not shown in the illustration) which are inserted beneath the magnet box, and which have a slider which supports the deflector at the height of the auxiliary suspended magnet, and at any desired distance.

The constants of this magnetometer and of magnet 19L were determined by the writer in December, 1893, as follows (in C. G. S. units):

Scale value magnet (19L)	1 division = 2.′00 of arc.
Corrected distance on deflecting bars, at mark 35 cm.	= 35.020 cm.
Corrected distance on deflecting bars, at mark 49 cm.	= 49.020 cm.
Temperature coefficient	$q = 0.00049$ for 1° C.
Induction coefficient	$k = 0.0125$.
Distribution coefficient	$P = -4.55$.
Moment of inertia at 10.°5 C.	$M = 178.38$.

These values were used in the computations, excepting that for P. This coefficient was computed from the present series of observations, with the result $P = -3.80$. The mean of this and the preceding determination, or $P = -4.18$, was used.

For fear that the great dip in these high latitudes might affect the horizontal force determinations by drawing the oscillating magnet out of the horizontal plane, in some of the observations at Ashe Inlet, Godhavn, and Umanak, the south end of magnet 19L was weighted with a small copper balancing ring, whose weight was 0.349 grams, outer radius 14.0 mm., inner radius 12.0 mm., length 0.9 mm. At Ashe Inlet and Godhavn the distance from center of ring to center of magnet was 20 mm., and at Umanak 22.5 mm., the endeavor being to so place it as to make the magnet horizontal. For the first distance, the moment of inertia was computed to be 1.693, and for the second, 2.064, using the formula $I = W[\frac{1}{3}(x_2^2 + x_2x_1 + x_1^2) + \frac{1}{4}(r_2^2 + r_1^2)]$, where r_2 is outer radius of ring, r_1 inner radius, x_2 distance center of oscillation to outer end of ring, and x_1 to inner end. Where the balancing ring was used, its moment of inertia must of course be added to that of the magnet and stirrup, in the formula for time of oscillation. A comparison of results for the horizontal component of the earth's magnetic force (H) from observations on the same day, made

with and without the balancing ring, indicates that the error due to lack of horizontality is at least very small.

	Results for H (in dynes). With ring.	Without ring.
Godhavn, August 3	0.0819	0.0819
Umanak, August 14	0.0783	0.0782
Umanak, August 15	0.0783	0.0782
Umanak, August 18	0.0791	0.0792

Besides the magnetic instruments proper, the chronometers and other auxiliary instruments belonging to the pendulum apparatus were used when required. The observing tent, which was suitable for astronomical or magnetic work, was used for the latter purpose at only one point (Umanak). At the other points the magnetic instruments were in the open air, either because the time was too short, or the tent was otherwise employed. Several times this arrangement was not satisfactory because of the high winds and otherwise unfavorable weather.

SECTION 6. *Magnetic Observations and Computations.* — For the complete determination of the three magnetic elements, declination, dip and horizontal force, the system generally employed in the field work of the Coast and Geodetic Survey with portable instruments was followed. Illustrative examples (taken from this season's work) of each of the steps involved, both in the observations and computations, are given in Part IV of this report, Sections 19–22. Complete instructions for such observations, adjustments of instruments, etc., are given by Mr. Schott in Appendix No. 8 of the Report United States Coast and Geodetic Survey for 1881. The theory of the various corrections involved (with the exception of that for induction[1]) is given by Professor Nipher in his little volume on the "Theory of Magnetic Measurements."

The operations included in a complete day's observations were as follows, about in the order named: 1. Early in the morning, reading of the horizontal magnet at intervals of about fifteen minutes to obtain the easterly elongation, which occurs between 7 and 9 A. M. in ordinary latitudes, but is quite variable in these northern regions. The positions of the magnet were of course referred to some terres-

[1] For this, reference may be made to Report Coast and Geodetic Survey for 1869, App. No. 9, p. 200; also Proc. Royal Society of London, 26, p. 221; also Lamont's "Handbuch des Erdmagnetismus," p. 152.

trial mark which was observed before and after the magnet readings. 2. Observations of the sun's azimuth and altitude (near the prime vertical if possible) to obtain the azimuth of the mark, usually made during some interval of the declination observations. 3. Determination of the axis of the magnet by alternate readings in direct and inverted position. 4. Determination of the time of oscillation of the magnet. 5. Measurement of the angle of deflection of the auxiliary magnet, as caused by the principal magnet at right angles to it, usually two sets at different distances, and followed if time permitted by another set of oscillations. 6. Determinations of the dip, complete sets with two independent needles. 7. Commencing about noon horizontal magnet readings, repeated at intervals of about fifteen minutes, to obtain the afternoon westerly elongation which occurs in ordinary latitudes from 1 to 2 P. M. 8. Sun observations for azimuth repeated late in the afternoon, for the reason that a combination of morning and afternoon azimuths eliminates the effect of an uncertainty in latitude.

Weather conditions and the limited amount of time available, rendered changes and curtailments of this program necessary in some cases. In others the plan was enlarged, the observations extended to two or three days, and the declination observations continued at somewhat irregular intervals throughout the day. At the northern stations it would have been of interest to continue the latter throughout the twenty-four hours to study the daily changes in declination, but this was not practicable with the other work on hand. At Umanak the true meridian was derived from a meridian line laid out with the meridian telescope. At Turnavik, Ashe Inlet, and Niantilik (second observation) only oscillation observations were made to determine the horizontal force. These were treated relatively, comparing the time of oscillation of the magnet at each of these stations with that at both the preceding and following stations where the force was completely determined, and allowing for the progressive change in the magnetic moment of the magnet. The rates of the chronometers for reducing the oscillation observations were obtained from the star observations with the meridian telescope in connection with the pendulum work at Sydney and Umanak, and for the remaining stations were derived from the intermediate traveling rates of the chronometers.

Section 7. *Results of Magnetic Observations.* — The results of the magnetic observations for the different elements separately and for each day of observation are given in Tables B, C, and D, and a

general summary of all the results is given in Table E. In Table B, when the extreme declinations observed were assumed to be the elongations for the day, they are indicated by an asterisk (*), and in such cases the mean of the two elongations is taken as the mean declination for the day. When because of lack of time it was impossible to obtain these elongations, the declinations have been reduced to the mean of the day from such comparative data at other stations as was available, the references being given in the footnote. Where the declination observations were made more or less continuously, covering any considerable part of the day, the average declination for this interval is given in the table, this average being obtained graphically by plotting the observed values. For five days, on each of which the readings covered an interval of about twelve hours, the results are shown in the diagram (Figure 11), plotted to the same scale for the different places. The diagram for Niantilik indicates a considerable magnetic disturbance on the date of observation, as was also very apparent when the observations were in progress, for the needle would frequently move out of range of the telescope, necessitating the changing of the azimuth circle. There was a change of over three degrees in twenty minutes; at 7 h. 35 m. A. M., the needle pointed 60° 35′ W. of N., while at 7 h. 55 m., it pointed 63° 50′ W. of N., and the total range for the day was over four and a half degrees. Such disturbances, however, are not unprecedented in Arctic experience.[1] An inspection of the magnetograph records[2] of the United States Naval Observatory at Washington, for the dates corresponding to those on which observations were made at the northern stations, shows that there were no considerable magnetic disturbances at these epochs, excepting on September 18, 1896. On this date there was an unusual magnetic storm, the extreme range in declination at Washington being 38′ for the entire day, and 19′ for the portion of the day corresponding to

[1] In The Manual of Natural History, Geology and Physics of Greenland (London, 1875), it is stated that McClintock observed a change of 15°, and Sir Edward Belcher noted a disturbance of 27.°6 accompanying an aurora.

[2] Copies of these records for the dates in question were furnished by Commodore Phythian, Superintendent of the Naval Observatory.

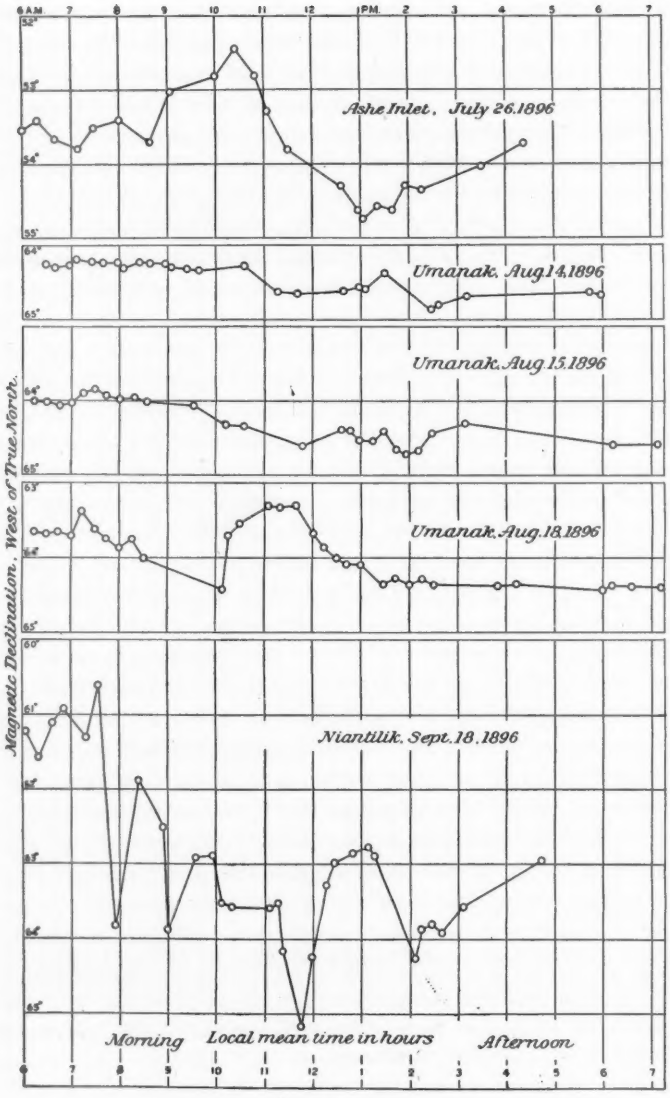


FIG. 11. DIURNAL CHANGES IN MAGNETIC DECLINATION.

the interval during which observations were made at Niantilik. The tracing for this latter interval is shown in Figure 11A, reduced to the same scale as is used in Figure 11, and there is also given the curve for part of a more normal day, July 26, the date on which observations were made at Ashe Inlet. It will be noted that the range in declination at Niantilik was nearly fifteen times as great as at Washington during the same interval. As the diagrams for the northern stations are plotted from individual observations at irregular intervals, they are of course not comparable in detail with the continuous Washington records. The last column in Table B gives the diurnal range for the

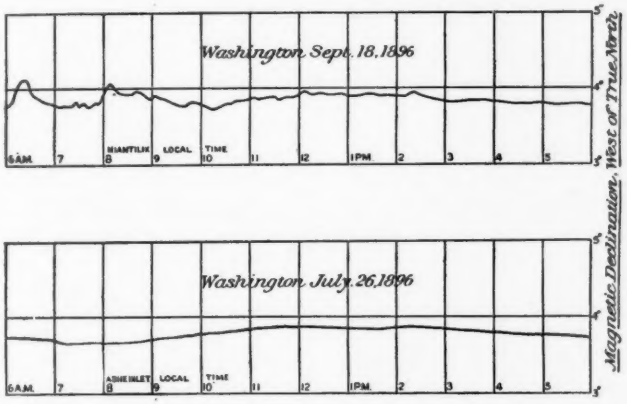


FIG. 11A. DIURNAL CHANGES IN DECLINATION AT WASHINGTON, D. C.

days on which elongations were obtained. These ranges cannot be considered as average values for the respective localities, being possibly affected by abnormal conditions on these particular days, as is evident in the case of Niantilik. At Umanak, Godhavn, and Sydney, declination observations were made at two or three neighboring points. At Sydney, the difference between the station of 1896 and Very's (1881) was insignificant for dip as well as for declination. At Umanak[1] the westerly declination increases about half a degree in going

[1] A considerable number of compass observations of declination were made about Umanak Fjord by Danish officers (Assistant Steenstrup and Lieutenant Hammer) in 1878 and 1879. The following passages translated from "Meddelelser om Grönland," 4th Part, p. 177 (Copenhagen, 1883), give some instances of the irregularity of the declination noted by them

from one to two hundred meters either north or south from the principal magnetic station. Near Godhavn the declination is slightly greater across the harbor at Watson's Bay than in the village, though the difference is not so great as was indicated by the English observations in 1875, which may have been made in somewhat different localities.

The total force (F) in the last column of Table E is derived from the horizontal force (H) and dip (θ) by the relation $F = \frac{H}{\cos \theta}$. All the results for H, F, and m are stated in C. G. S. units.

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in this region: "It is a familiar saying that the magnet needle on these shores is nearly dead, and that the magnetic declination, especially in trap rock regions, is so variable that for geographical measurements it is necessary to determine it for every bearing, for it changes with every setting up of the compass. Thus a small movement, only some few feet, effected on the Shades Islands a change of 5° in the measured declination; indeed, at Igdlorsuit upon Ubekjendt Island a movement from the houses up to the top of the mountain about 1,500 feet high, lying about 2,000 feet away, was sufficient to change the declination from 74.°0 to 34.°9. . . . In gneiss regions the local effect is not near so strong, but while the trap generally causes greater declinations than one would expect from the geographical position, gneiss on the contrary not unusually appears to give less declinations." It is further remarked that normal conditions can often be found only upon the ice.

TABLE B. — SUMMARY OF RESULTS OF MAGNETIC DECLINATION OBSERVATIONS.

Station.	Date. (Civil.) 1896.	Easterly Extreme.		Westerly Extreme.		Average Declination During Time of Observation.		Correction to reduce to mean declination.†	Adopted mean declination.	Diurnal range in declination.
		Local mean time.	Declination.	Local mean time.	Declination.	Interval included. Local mean time.	Average declination.			
		h. m.	° ′	h. m.	° ′				° ′	° ′
1. Halifax	July 6–7	7 31 A.M.	20 35.5* W.	12 46 P.M.	20 41.6* W	.....	.....	....	20 38.6 W	0 06.1
2. Sydney. (Station 1896) .	July 11	7 40 A.M.	24 41.4*	1 25 P.M.	25 01.3*	.....	.....	....	24 51.4	0 19.9
Sydney. (Station 1896) .	July 13	8 44 A.M.	24 49.8*	2 00 P.M.	25 01.1*	.....	.....	....	24 55.4	0 11.3
Sydney. (Station 1896) .	Mean.	.....	.....	.....	.....	.....	.....	....	24 53.4	0 12.4
3. Turnavik	July 20	8 53 A.M.	38 17.2	12 03 P.M.	38 34.4	h. m. h. m. 8 53 A.M. to 12 03 P.M.	° ′ 38 28.4 W.	— 2.0′	38 26.4	....
4. Ashe Inlet	July 26	10 23 A.M.	52 29.4*	1 08 P.M.	54 40.7*	6 07 A.M. to 4 28 P.M.	53 45.9	....	53 35.0	2 11.3
5. Godhavn	Aug. 3	3 17 A.M.	63 33.8	9 04 A.M.	61 37.3	2 08 A.M. to 9 21 A.M.	62 43.5	— 1.9	62 41.6	....
6. Watson's Bay	Aug. 3	.....	.....	.....	.....	10 05 A.M.	63 12.2	— 5.3	63 06.9	....
7. Umanak	Aug. 14	7 15 A.M.	64 06.6*	2 30 P.M.	64 49.2*	6 37 A.M. to 6 00 P.M.	64 26.8	....	64 27.9	0 42.6
Umanak	Aug. 15	7 30 A.M.	63 46.6*	2 00 P.M.	64 44.1*	6 20 A.M. to 9 05 P.M.	64 19.8	....	64 15.4	0 57.5
Umanak	Aug. 18	11 05 A.M.	63 16.1*	6 00 P.M.	64 28.8*	5 55 A.M. to 8 05 P.M.	64 04.3	....	63 52.5	1 12.7
Umanak	Mean.	.....	.....	.....	.....	.....	.....	....	64 11.9	0 57.6
8. Umanak, S. Meridian .	Aug. 21	.....	.....	.....	.....	5 30 P.M.	65 07.5	—22.5	64 45.0	....
9. Umanak, N. Meridian .	Aug. 21	.....	.....	.....	.....	6 00 P.M.	65 06.0	—28.0	64 38.0	....
5. Godhavn	Sept. 11	2 07 P.M.	63 14.0	6 20 P.M.	63 52.5	2 00 P.M. to 6 30 P.M.	63 34.4	—20.6	63 13.8	....
10. Niantilik	Sept. 18	7 35 A.M.	60 35.3*	11 40 A.M.	65 09.4*	5 35 A.M. to 3 40 P.M.	62 54.9	....	62 52.4	4 34.1
11. Sydney. (Station 1881) .	Sept. 26	.....	.....	.....	.....	4 25 P.M.	24 56.7	— 1.4	24 55.3	....

* The extreme declinations marked thus were assumed from their relation to the other observed values to be the eastern and western elongations respectively for the day. Where these elongations were obtained, their mean is taken as the mean declination for the day, without further correction.

† The corrections to reduce to mean declination were derived as follows: Turnavik, July 20. From table of corrections for Toronto (C. and G. S. Report, 1881, App. 8), allowing for difference in *H*. Godhavn and Watson's Bay, August 3. By comparison with three days' observations at Umanak. Umanak, S. and N. meridian, August 21. By direct comparison with principal magnetic station, Umanak. Godhavn, September 11. By comparison with three days' observations at Umanak. Sydney, September 26. From table of corrections for Toronto.

TABLE C.—SUMMARY OF RESULTS OF MAGNETIC DIP OBSERVATIONS.

	Station.	Date. 1896.	Epoch. Local mean time.	Magnetic Dip. Needle No. 1.	Magnetic Dip. Needle No. 2.	Mean of two needles.	Difference. No. 1–No. 2.
			h. m.	° ′	° ′	° ′	′
1.	Halifax	July 6	5 36 P.M.	73 53.2 N.	73 54.9 N.	73 54.0 N	−1.7
2.	Sydney. (Sta. 1896.)	July 11	11 50 A.M.	74 40.8	74 40.0	74 40.4	+0.8
	Sydney. (Sta. 1896.)	July 13	11 16 A.M.	74 37.2	74 36.4	74 36.8	+0.8
	Sydney. (Sta. 1896.)	Mean.	.....	74 39.0	74 38.2	74 38.6	....
3.	Turnavik	July 20	11 19 A.M.	79 32.9	79 28.8	79 30.8	+4.1
4.	Ashe Inlet	July 26	12 09 P.M.	83 54.0	83 59.6	83 56.8	−5.6
5.	Godhavn	Aug. 3	5 14 A.M.	81 47.2	81 46.5	81 46.8	+0.7
7.	Umanak	Aug. 14	6 54 P.M.	82 03.2	82 01.7	82 02.4	+1.5
	Umanak	Aug. 15	11 16 A.M.	82 04.0	82 00.5	82 03.2	+3.5
	Umanak	Aug. 18	9 26 A.M.	81 55.6	81 55.9	81 55.8	−0.3
	Umanak	Mean.	.....	82 00.9	81 59.4	82 00.1	....
5.	Godhavn	Sept. 11	4 34 P.M.	81 40.2	81 41.0	81 40.6	−0.8
10.	Niantilik	Sept. 18	10 42 A.M.	83 55.0	83 54.5	83 54.8	+0.5
11.	Sydney. (Sta. 1881.)	Sept. 26	4 52 P.M.	74 35.8	74 38.2	74 37.0	−2.4

TABLE D.—SUMMARY OF RESULTS OF HORIZONTAL FORCE OBSERVATIONS.

	Station.	Date, 1896.	Epoch. (Local mean time.)	Horizontal magnetic force *H*.	Magnetic moment of magnet 19L. *m* at 16°.7 C.*
			h. m.	Dyne.	
1.	Halifax	July 6	4 24 P.M.	0.1631	418.5
	Halifax	July 6	4 30 P.M.	0.1633	418.1
	Halifax. (Means.)	.....	.....	0.1632	418.3
2.	Sydney	July 11	10 25 A.M.	0.1548	416.3
	Sydney	July 11	10 32 A.M.	0.1546	416.5
	Sydney	July 13	9 48 A.M.	0.1548	416.6
	Sydney	July 13	10 08 A.M.	0.1548	416.4
	Sydney. (Means.)	.....	.....	0.1547	416.4
3.	Turnavik	July 20	10 44 A.M.	0.1074	.....
	Turnavik	July 20	11 48 A.M.	0.1074	.....
	Turnavik. (Means.)	.....	.....	0.1074	.....
4.	Ashe Inlet †	July 26	11 24 A.M.	0.0637‡	.....
5.	Godhavn	Aug. 3	2 58 A.M.	0.0819‡	413.6
	Godhavn	Aug. 3	3 21 A.M.	0.0819	413.7
	Godhavn. (Means.)	.....	.....	0.0819	413.6
7.	Umanak	Aug. 14	10 32 A.M.	0.0782	413.1
	Umanak	Aug. 14	11 18 A.M.	0.0783‡	412.3
	Umanak	Aug. 15	9 17 A.M.	0.0783‡	411.7
	Umanak	Aug. 15	9 32 A.M.	0.0779	410.0
	Umanak	Aug. 15	10 14 A.M.	0.0785	411.9
	Umanak	Aug. 18	6 35 P.M.	0.0793	410.5
	Umanak	Aug. 18	7 13 P.M.	0.0791‡	411.5
	Umanak	Aug. 18	7 26 P.M.	0.0790	411.1
	Umanak (Means.)	.....	.....	0.0786	411.5
5.	Godhavn	Sept. 11	3 15 P.M.	0.0825	412.6
10.	Niantilik	Sept. 18	6 47 A.M.	0.0653	410.1
	Niantilik	Sept. 18	2 57 P.M.	0.0668	.....
	Niantilik. (Means.)	.....	.....	0.0660	.....

* The magnetic moment of this magnet as determined in December, 1893, soon after the completion of the instrument, and before its use in the field, was 491.3 at 16.°7 C.

† Only a portion of a set of oscillations was obtained at this station.

‡ In the observations marked thus, the south end of the magnet was weighted with a small balancing ring.

TABLE E. — Summary of Results of Magnetic Observations.

Station.	Latitude, north.	Longitude west of Greenwich.	No. of days observations.	Date.	Declination.	Diurnal range in declination.	Dip, θ.	Horizontal force, H.	Total force, F.
	° ′	° ′		1896.	° ′	° ′	° ′	Dyne.	Dyne.
9. Umanak, Greenland, N. Meridian . . .	70 40.6	52 08.4	1	Aug. 21.	64 38.0 W.	.....	.....	.....	.....
8. Umanak, Greenland	70 40.5	52 08.4	3	Aug. 14, 15, 18.	64 11.9	0 57.6	82 00.1 N.	0.0786	0.5649
7. Umanak, Greenland, S. Meridian . . .	70 40.4	52 08.4	1	Aug. 21.	64 45.0	.....	.....	.....	.....
6. Watson's Bay, Greenland	69 14.6	53 31.7	1	Aug. 3.	63 06.9	.....	.....	.....	.....
5. Godhavn, Greenland	69 14.1	53 31.2	2	Aug. 3, Sept. 11.	62 57.7	.....	81 43.7	0.0822	0.5714
10. Niantilik, Cumberland Sound	64 53.5	66 19.5	1	Sept. 18.	62 52.4	4 34.1	83 54.8	0.0660	0.6224
4. Ashe Inlet, Hudson Strait	62 32.8	70 35.3	1	July 26.	53 35.0	2 11.3	83 56.8	0.0637	0.6040
3. Turnavik, Labrador	55 14.6	59 20.3	1	July 20.	38 26.4	.....	79 30.8	0.1074	0.5901
11. Sydney, Cape Breton. (Station 1881.) . .	46 08.6	60 11.7	1	Sept. 26.	24 55.3	.....	74 37.0	.....	.....
2. Sydney, Cape Breton. (Station 1896.) . .	46 08.5	60 11.8	2	July 11, 13.	24 53.4	0 12.4	74 38.6	0.1547	0.5842
1. Halifax, Nova Scotia	44 39.5	63 35.0	1	July 6, 7.	20 38.6	0 06.1	73 54.0	0.1632	0.5885

SECTION 8. *Comparison with Earlier Magnetic Observations.* — In Table F is given a collection of former magnetic observations made at or in the vicinity of these stations.[1] For many of these points it is probable that this data is quite incomplete, for results of this nature are published in a wide range of local literature often difficult of access. With the exception of Halifax and Godhavn the observations

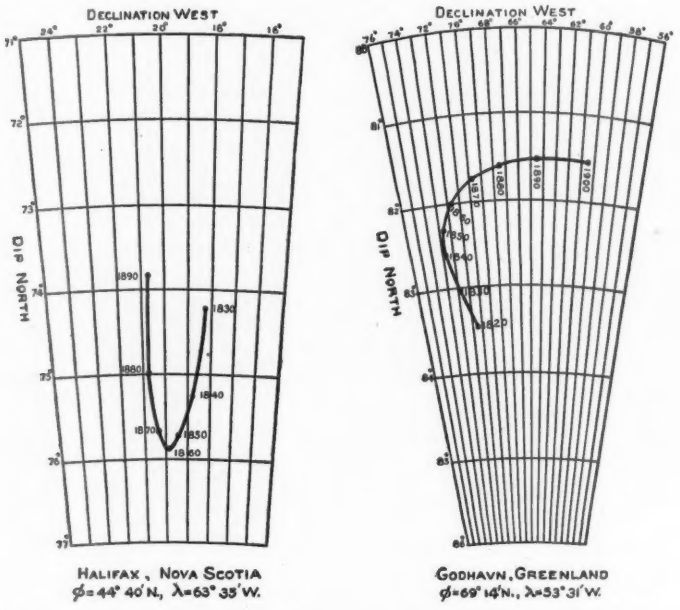

FIG. 11B. SECULAR CURVES, REPRESENTING THE MOTION OF THE NORTH END OF A FREELY SUSPENDED MAGNETIC NEEDLE.

are scarcely complete enough, nor do they cover a sufficiently long interval of time to give satisfactory analytical expressions for the secular variation of the declination and dip. For most of the stations, however, the data is sufficient to clearly indicate the present tendency in the change of the magnetic elements. It appears that at all these points (omitting Niantilik, for which no earlier information was found)

[1] The writer is indebted to Dr. L. A. Bauer, editor of "Terrestrial Magnetism," for information in regard to some earlier observations.

the westerly declination is diminishing, the northerly dip is diminishing, the horizontal force is increasing, and the total force is decreasing.

Analytical expressions for the change of declination and dip for Godhavn and Halifax[1] were derived from the results given in Table F, after applying an estimated correction to the observations at Whalefish Islands to refer them to Godhavn. With these formulas the declination and dip were computed for each tenth year, and the curves shown in Figure 11B plotted, representing the motion of the north end of a freely suspended needle (half length 61 cm. or 24 inches) as viewed by an eye at the center of the needle. This method of representation shows the movements in declination and dip in their proper relation. For both these stations the motion of the needle is in a clockwise direction, thus agreeing with the general law deduced by Dr. L. A. Bauer.[2]

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[1] Mr. Schott has derived the following expression (which was used) for the change of the magnetic declination at Halifax: $D = +16°.18 + 4°.53 \sin(1°.0\, m + 46°.1)$ where D is the declination at a desired time, t expressed in years and fractions of a year (+ for westerly declination), and $m = t - 1850.0$ (Report U. S. C. and G. Survey for 1888, App. No. 7, p. 224). For 1896-7 this formula gives $D = 20°\ 42'$ W., differing only $3'$ from the observed value.

[2] "Beiträge zur Kenntniss des Wesens der Säcular-Variation des Erdmagnetismus," Berlin, 1895; also "On the secular motion of a free magnetic needle," Physical Review, Vol. II, No. 12, Vol. III, No. 13.

TABLE F.—COLLECTION OF MAGNETIC OBSERVATIONS AT OR NEAR STATIONS OCCUPIED IN 1896.

No.	Date.	Declination.	Dip.	Horizontal force.	Total force.	Observer.	Remarks and References.
	Umanak, Greenland. Latitude, 70° 40′ N. Longitude, 52° 08′ W.						
		° ′	° ′	Dyne.	Dyne.		
1	1823–4.	70 50 W.	.....	.....	.....	Graah	Meddelelser om Grönland, 4th Part, p. 282.
2	1878.	67.9	.....	.....	.....	Steenstrup and Hammer.	Meddelelser om Grönland, 4th Part, p. 252. Steenstrup and Hammer give several other observations of declination in this vicinity, as follows: 1879, ½ mile north of Umanak, on ice, 70°.2 W. 1878, Umanak, Little Lookout, 68.6. 1879, Umanak, Little Lookout (mean two obs.), 67.8. 1879, Umanak, on ice (mean three obs.), 69.3.
3	1896, Aug. 14–18.	64 12	82 00 N.	0.0786	0.5649	Putnam	
	Godhavn, Greenland. Latitude 69° 14′ N. Longitude, 53° 31′ W.						
1	1824.5.	70 24	82 54	....	....	Parry	At Whalefish Islands, lat. 68° 59′ N.; long. 53° 18′ W. Phil. Trans. Royal Society, Vol. 90, p. 414.
2	1836.5.	....	82 23	....	....	James Ross	
3	1848.5.	....	82 24	....	....	Ross and Robinson . .	
4	1850.5.	....	82 12	....	....	Allen	
5	1851.5.	....	....	....	0.5602	Ommanney	
6	1852.5.	70 47	82 10	....	....	Belcher	
7	1853.5.	....	81 48	....	0.5634	Bellot	Phil. Trans., Vol. 90, p. 414.
8	1858.5.	73 28	....	....	....	McClintock	At Whalefish Islands. Phil. Trans. Vol. 90, p. 414.
9	1861, Aug. 31–Sept. 7.	....	81 51	0.0812	0.5731	Radcliff	Station in garden rear of Inspector's house. Hayes' Polar Expedition. Smithsonian Contrib., Vol. 15, p. 105.
10	1875, July 9–13.	67 13	81 48	0.0832	0.5789	"Alert"	Near flagstaff.
11	1875, July 8–12.	68 20	81 52	0.0816	0.5740	"Discovery"	Opposite side of harbor to flagstaff.
12	1876, Sept. 27.	68 20	....	....	....	"Discovery"	Arctic Expedition of 1875–76. Proc. Royal Society, Vol. 29, p. 29. Remark on p. 29: "The values of the declination and inclination observed at various stations around the harbor of Godhavn showed considerable differences, evidently caused by local magnetic distui bance."
13	1884, July 8.	65 35	....	....	....	Sebree	Greely Relief Expedition, Naval Prof. Papers No. 19, p. 94.
14	1896, Aug. 3, Sept. 3.	62 58	81 44	0.0822	0.5714	Putnam	Near Inspector's garden.
15	1896, Aug. 3.	63 07	....	....	....	Putnam	Opposite side of harbor at Watson's Bay.
	Niantilik, Cumberland Sound. Latitude, 64° 54′ N. Longitude, 66° 20′ W. No record found of previous observations.						
	Ashe Inlet, Hudson Strait. Latitude, 62° 33′ N. Longitude, 70° 35′ W.						
1	1884. Aug. 2.	....	84 16	....	....	Gordon	Report of Second Hudson's Bay Expedition, 1885, p. 78.
2	1888.	55 30	....	....	....		British Admiralty chart, No. 1221.
3	1896, July 26.	53 35	83 57	0.0637	0.6040	Putnam	

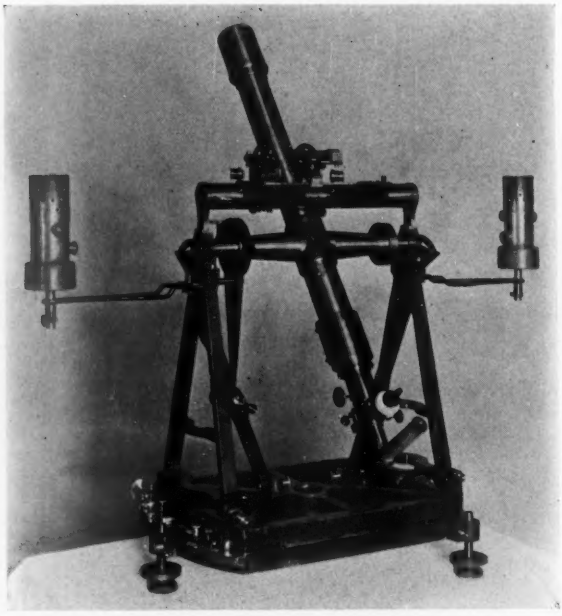


FIG. 12. MERIDIAN TELESCOPE.

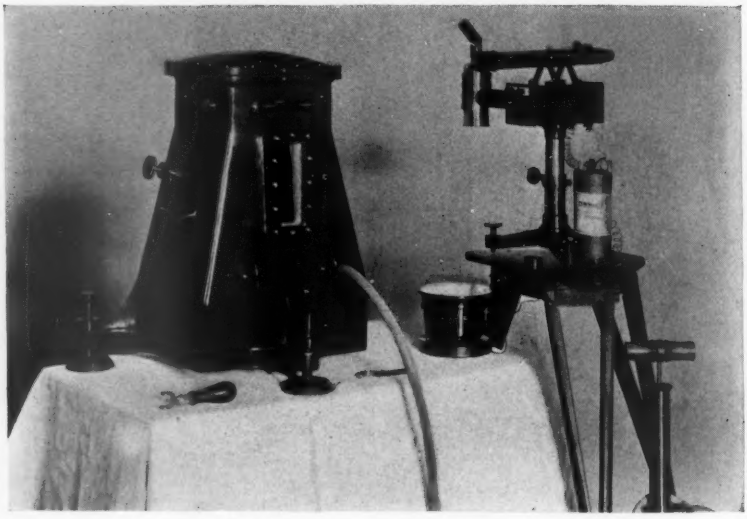


FIG. 13. PENDULUM APPARATUS, GENERAL VIEW.

TABLE F.—COLLECTION OF MAGNETIC OBSERVATIONS AT OR NEAR STATIONS OCCUPIED IN 1896.—*Continued.*

No.	Date.	Declination.	Dip.	Horizontal force.	Total force.	Observer.	Remarks and References.
	Turnavik, Labrador, Latitude, 55° 15′ N. Longitude, 59° 20′ W.						
		° ′	° ′	Dyne.	Dyne.		
1	1881, July 28, 29.	40 23 W.	79 56 N.	0.1034	0.5916	Very	Report U. S. C. and G. Survey, 1881, p. 192.
2	1896, July 20.	38 26	79 31	0.1074	0.5901	Putnam	
	Sydney, Cape Breton. Latitude, 46° 09′ N. Longitude, 60° 12′ W.						
1	1848.5.	23 41	....	....	....	Keely	Position given, latitude 46° 17′, longitude 60° 23′. Phil. Trans. Vol. 90, p. 384.
2	1862.5.	....	76 03	....	....	Shadwell	Position given, latitude 46° 16′, longitude 60° 08′. Phil. Trans. Vol. 90, p. 384.
3	1881, Oct. 21, 22.	25 12	75 10	0.1515	0.5918	Very	Report U. S. C. and G. S., 1881, p. 192.
4	1896, July 11, 13.	24 53	74 39	0.1547	0.5842	Putnam	
5	1896, Sept. 26.	24 55	74 37	....	....	Putnam	At Very's station of 1881.
	Halifax, Nova Scotia. Latitude, 44° 40′ N. Longitude, 63° 35′ W.						
1	1604–1612.	16½ W.	....	....	....	Champlain	All of the values for Halifax excepting the last one are taken from two papers by Assistant C. A. Schott, Report C. and G. Survey for 1888, App. No. 7, p. 191, and Report C. and G. Survey for 1885, App. No. 6, p. 226. The individual references are there given.
2	1630 about.	14	....	....	....		
3	1700.	13 or 12½	....	....	....		
4	1750.	12	....	....	....		
5	1756.	12 50	....	....	....		
6	1775.	13 35	....	....	....		
7	1798.	16 30	....	....	....		
8	1818. (?)	17 28	....	....	....		
9	1821, June–Nov.	17 36	....	....	....		
10	1833.	17 30	....	....	....		
11	1834, May 27.	....	75 33	0.1485	0.5966	Home	
12	1837, June 7.	....	74 58			Home	
13	1838.5.	....	74 45	....	....	Estcourt	
14	1847.5.	....	75 37	....	0.6026	Keely	
15	1852–53.	18 10	....	....	....	Bayfield	
16	1852–53.	18 51	....	....	....	Hill	
17	1860, July 22.	19 55	....	....	....	Orlebar	
18	1866, April.	21 06	....	....	....		
19	1873, May 13–16.	21 35	74 48	0.1561	0.5954	Maclear and Bromley . .	
20	1879, Sept. 8, 10.	20 43	74 39	0.1592	0.6012	Baylor	
21	1881, Nov. 2.	....	74 29	0.1595	0.5962	Very	
22	1896, July 6, 7.	20 39	73 54	0.1632	0.5885	Putnam	

Part III. Pendulum Observations.

Section 9. *Instruments for the Measurement of the Relative Force of Gravity.* — The apparatus belonging to the Coast and Geodetic Survey used for this purpose, was nearly the same as was employed in recent work in the United States, and more particularly in the trans-continental series of observations in 1894. It comprised the following:

Meridian Telescope No. 13 (Figure 12), aperture 5.1 cm.; focal length, 65.8 cm.; magnifying power, 46. This is a very portable combination instrument with folding frame, and is suitable for either time altitude or azimuth observations.

Chronometers Nos. 1,823 (sidereal), 1,842 (mean time), and 177 (mean time). All were provided with electrical break-circuit attachments, for use with the pendulum flash apparatus; also with condensers to prevent sparking.

Pendulum apparatus "*A*" (Figures 13 to 22) comprising three invariable half-second pendulums *A*4, *A*5, and *A*6, one dummy or temperature pendulum, an air-tight brass case, thermometers, manometer, air pump, flash apparatus, dry cells, and weight, pulley and microscope for measuring flexure. There was also a small astronomical observing tent in which the meridian telescope was mounted. At one point a small circular tent was used for the pendulum apparatus.

The essential requisite in pendulum observations for the measurement of the relative force of gravity, is the determination of the period of oscillation as precisely as may be, and also of all the variable conditions that affect that period. Because these conditions can thus be controlled very much better, this apparatus includes an air-tight case in which the pendulums are swung. The pendulums are made of an alloy of copper and aluminum, weighing approximately 1,200 grams each, and having a length of about 248 mm. from center of bob to point of suspension (the three in the set are intentionally slightly different in length). Their shape is such as to give them strength, and small resistance to the air in oscillating. They have an agate plane set in the head which rests on the agate knife-edge on which they are swung. This so-called knife-edge is formed by carefully ground planes meeting at an angle of 130°, thus insuring greater permanency than could be expected with a sharper edge. The knife-edge is set in a solid metal plate (*m* Figure 15) which is secured to

the shelf *n* in the pendulum case. As a check in case of injury there are two such knife-edges with this apparatus, marked *I* and *II*, each in its own plate, either of which may be set in the case. Pendulum *A*4 was always swung on knife-edge *II*, and *A*5 and *A*6 on knife-edge *I*, the advantage in using several distinct knife-edges as well as distinct pendulums being that by the relation between the independent results thus obtained, a continual check on the constancy of the instruments is furnished. The pendulum may be lowered on to the knife-edge or lifted from it without opening the case, by means of the screw *q* which

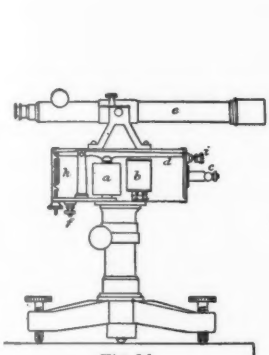


Fig. 14
Flash Apparatus

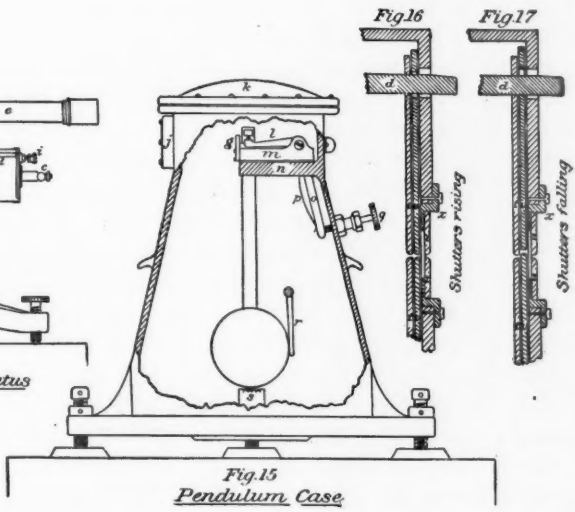
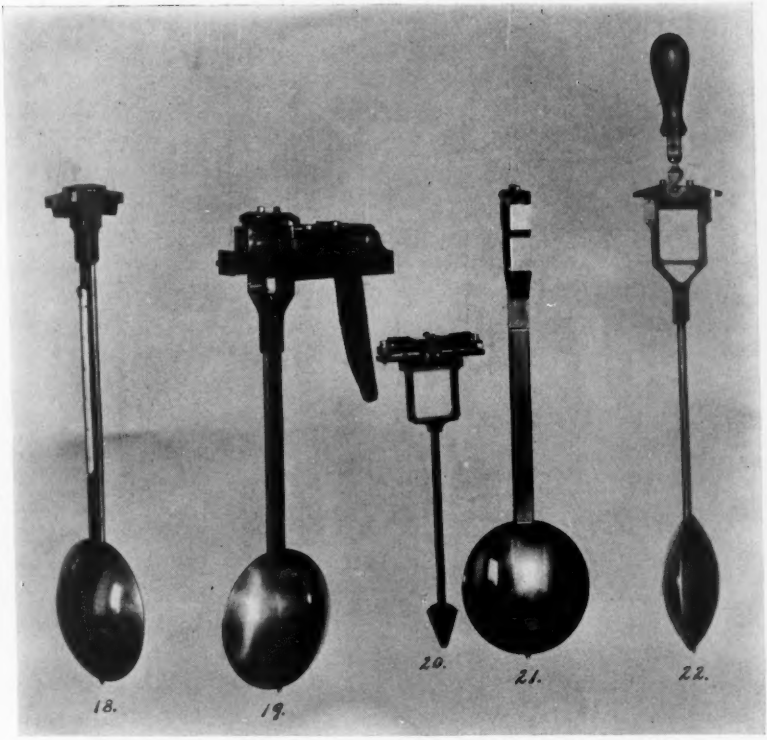


Fig. 15
Pendulum Case

presses against the arm *o*. This arm is rigidly attached to the frame *l* which carries two points on its extremity which lift the pendulum off the edge, fitting into corresponding sockets in its head. The pendulum is set in oscillation or brought to rest by the arm *r*, which is controlled by a lever arm on the outside of the case. There is a scale below the pendulum, and a telescope (not shown) mounted on the side of the case for reading the arc of oscillation. The case is supported by three large foot screws resting on heavy foot plates which are to be cemented to the foundation. The case is leveled in the plane of oscillation by the pendulum itself as shown by the reading of the tip of the pendulum on the scale beneath. In the transverse plane it is

leveled by a small level mounted in a short pendulum (Figure 20), which may be reversed on the knife-edge. On the opposite side of the case and parallel with the swinging pendulum, there is hung a "dummy" or temperature pendulum (Figure 18), so held that it cannot oscillate. This dummy is of the same material, mass, and general shape as the pendulums, and has mounted on its stem a thermometer whose bulb is buried in the stem near the bob, being packed with metal filings to bring it into close contact, the endeavor being in this way to obtain as near as possible the actual temperature of the swinging pendulum. Near the dummy is also placed a free thermometer and a mercury manometer which shows pressures from 10 cm. down. The case is provided with windows on three sides for observing purposes, and with a removable cover which forms an air-tight joint, with a little oil and tallow rubbed on the carefully ground contact surfaces. The air is exhausted through stop cocks on the side of the case. With the new portable air pump, weighing only about 6 pounds (2.7 kilograms), the pressure in this case may be reduced to the standard (about 6 cm.) in two or three minutes.

The flash apparatus (shown in Figures 13 and 14) is used in observing coincidences between the pendulum and a break-circuit chronometer, from which coincidences the time of oscillation is obtained in terms of the chronometer. The break-circuit chronometer has attachments so that it can be included in an electrical circuit, and is provided with mechanism that will break that circuit at the end of each second (or sometimes each even second). The chronometer is made to throw a flash of light every second by means of the electro-magnet *a*, the armature *d*, and the two shutters carried by the end of this armature and shown in the enlarged sections (Figures 16, 17). When the circuit is broken, the spring *h* causes the armature *d* to rise, and for an instant the slits in the shutters *t* and *v* are in line with the slit ir the front of the box *z* (as in Figure 16), and a flash of light is thrown, this light being reflected by the mirror *b* from a lamp mounted on the side of the box; when the circuit is closed the shutters in descending so interfere as to cut off the light (as shown in Figure 17) so that the slit is only illuminated for a brief instant at each break of the circuit. The flash apparatus carries above it a telescope *e*, and is mounted at a convenient distance from the pendulum case in such position that the illuminated slit may be seen in the telescope as reflected from a mirror which is carried on the head of the pendulum,



FIGS. 18–22.

Fig. 18. Dummy or Temperature Pendulum with Thermometer.
Fig. 19. Pendulum and Knife-edge Plate, showing mode of suspension.
Fig. 20. Leveling Pendulum.
Fig. 21. Half-second Pendulum, side view.
Fig. 22. Half-second Pendulum, front view.

and which is seen through the window j in the front of the case. There is also a fixed mirror g attached to the knife-edge plate, but adjustable in position. This is so adjusted that the image of the slit as seen in the telescope, reflected from the fixed mirror, shall be in the same horizontal line and slightly overlapping that reflected from the pendulum mirror when the pendulum is hanging freely at rest. When the pendulum is swinging, the image as reflected from the pendulum mirror will change its position relatively to that of the fixed mirror as seen in the field of the telescope, because of the fact that the pendulum makes a double oscillation in a little more than a sidereal second, and hence will be found slightly behind its former position at the end of each second when the flash is thrown. The moving image will, therefore, appear to travel up and down across the field of the telescope by successive jumps, and coincidences are observed by noting the time when the two images are in the same horizontal line. It is evident that in the interval between two occurrences of this phenomenon the pendulum has made one less than twice as many oscillations as the chronometer has beat seconds, and that in an interval of time between the first and last of a number of coincidences, the number of oscillations of the pendulum will be twice the number of seconds (s) less the number of coincidence intervals (n), so that the time of a single oscillation is readily derived from the relation $P = \frac{s}{2s - n}$. The elegance of the coincidence method lies in the fact that a small error in noting the time of coincidence has little effect on P. At the northern stations the period of the pendulums was so shortened because of the increased force of gravity, that it closely approached the sidereal half second, so that the coincidence intervals would have been inconveniently long. Mean time chronometers were therefore used at these points. The pendulums are faster than the mean time half second, and therefore gain one oscillation in a coincidence interval, and the formula for the period becomes $P = \frac{s}{2s + n}$.

Section 10. *Methods of Observation with Pendulum Apparatus.* — The plan proposed to be followed in this work was the same as that used before, to begin the swings of the pendulum immediately after star observations for time were obtained, and to end them after star observations forty-eight hours later, or in case these failed, to continue until time observations were obtained. This plan permit-

ted of the making of six swings each eight hours in length, each of the three pendulums being swung in reversed and direct positions. Unfavorable weather and other conditions, of course, modified this plan; thus at Umanak and at Washington in June the swings were continued for four days because the time observations were lost on intermediate nights, and at Ashe Inlet and Niantilik but three swings covering a single day were made, and no complete time observations were obtained. An example of the observations and computations for a single swing is given in Section 24. The pendulums were swung under as nearly uniform conditions as possible at the various stations. The pressure in the case was reduced to about 60 mm., the total arc of oscillation to commence with was about 53′, falling off to about 20′ at the end of the swing, and the apparatus was mounted on stable foundations, and when practicable in places where the variations of temperature would be small. In general, two chronometers were used, coincidences being noted alternately with each by means of a suitable switch arrangement. Only sufficient coincidences were observed at the beginning and end of the swing, so that the total number which had occurred might be correctly estimated. Intermediate coincidence and temperature observations were made when the variations in conditions were large. Since with the small arcs used the movement of the image from second to second is slow, the times of contact and separation between the moving and fixed images were noted, and the mean taken for the time of coincidence. To eliminate possible errors of adjustment, coincidences were observed with the image moving in opposite directions, "up" and "down," and all results are based on a combination of these. The flexibility of the support was measured statically by noting with an independently supported microscope the movement of a scale mounted above the knife-edge when a horizontal force of 1.5 kilograms was applied in the plane of oscillation of the pendulum. This force was applied by having a weight suspended by a cord running over a pulley, the other end of the cord being attached immediately behind the knife-edge. The movement of the scale in microns was noted when the weight was alternately applied and relieved. The following table gives the support for the pendulum case and the flexure at the various stations, the values for Ashe Inlet and Niantilik being estimated by comparisons with similar conditions elsewhere. The flexure in all cases was quite small, due to the low and solid supports.

Station.	Support.	Flexure microns.
Washington, D. C.	Massive brick pier with capstone	1.0
Sydney, Cape Breton . . .	Low brick and cement pier against foundation wall .	1 5
Ashe Inlet, Hudson Strait .	Bed rock	[1.0]
Umanak, Greenland	Low brick and cement pier on stone floor	2 0
Niantilik, Cumberland Sound,	Bed rock	[1.0]

SECTION 11. *Time Observations and Chronometer Rates.* — The chronometer corrections were determined by star observations with an astronomical transit instrument set in the meridian, the transits across the meridian of about eight stars each evening being observed, half in each position of the instrument. An example of one night's time observations and the computation is given in Section 23. At Washington a large longitude transit was used and the observations recorded on a chronograph. At the northern stations a smaller meridian telescope was employed, and the observations made by the eye and ear method, that is, the beats of the chronometer were noted by ear while the eye followed the movement of the star across the lines of the telescope. The latter instrument was set in the meridian by use of a table giving the azimuth and altitude of Polaris for any hour angle.[1] By setting the telescope at the given altitude and moving it slowly near the supposed position, Polaris could be readily found, even before sunset, and then the angle of its azimuth set off on the horizontal arc provided for that purpose. Of course only one chronometer was used in the time observations, and the comparisons with the others were obtained by noting by ear the coincidences of beats between mean time and sidereal chronometers. This is an accurate and convenient method, such coincidences coming at intervals of a little over three minutes, because of the gain of sidereal on mean time.

As already mentioned, the time observations at Ashe Inlet and Niantilik failed because of unfavorable weather and the limited length of stay. The adopted rates at these points were obtained by combining the rates at the preceding and following stations and the traveling rate, giving equal weight to the chronometers. In each case it is estimated that the adopted rate is uncertain by at least a second of time, which would correspond to an uncertainty of about $\frac{1}{40000}$ in g (or .025 dyne or cm.). As the temperatures at Ashe Inlet and Niantilik were lower than the average, and chronometers usually run slower at low temperatures, it is probable that these adopted rates are too fast, and

[1] See Appendix 10, Report U. S. C. and G. Survey for 1895.

that consequently the periods of the pendulums are too small, and the resulting force of gravity too large for these two stations.

The rate at Ashe Inlet was derived as follows:

		Chronometers.	
	1823 S. T	1842 M. T.	177 M. T.
	s.	s.	s.
Rate at Sydney, July 10–12	+1.62	—0.24	....
Traveling rate July 16–October 3 (omitting Umanak),	+2.51	+2.17	+3.70
Rate at Umanak, August 7–August 20	+2.29	+1.43	+4.82
Means	+2.14	+1.12	+4.26
Rates of mean time chronometers, derived from above average rate of 1823, and comparisons before and after pendulum observations		+0.80	+4.20
Adopted rates (weighted mean giving half weight to latter values, so as to give equal effect to all three chronometers)		+1.01	+4.24

The rate at Niantilik was derived as follows:

	Chronometers.	
	1833 S. T.	1842 M. T.
	s.	s.
Rate at Umanak, August 7–20	+2.29	+1.43
Traveling rate, July 16–October 3 (omitting Umanak),	+2.51	+2.17
Rate at Washington, October 6–15	+1.91	+1.59
Means	+2.24	+1.73
Rate of 1842 derived from above average rate of 1823 and comparisons before and after pendulum observations		+0.82
Mean, adopted rate		+1.28

Table G gives a summary of the rates of the chronometers which were used directly in the pendulum observations at the different stations. In some cases two chronometers were employed, and in others only one. At Sydney one mean time and one sidereal chronometer were used, and at the other three northern stations mean time chronometers exclusively were used in the pendulum observations directly. This became necessary because the increase in the force of gravity so diminished the period of the pendulums that it approached closely to the sidereal half second, and the coincidence intervals with a sidereal chronometer would have become inconveniently long, but the pendulums were enough faster than a mean time chronometer to give convenient coincidence intervals with it. The rates are all referred to sidereal time by adding $+236.555$ to the mean time rate, as expressed in mean time seconds on mean time, after reducing the latter to sidereal seconds by adding the necessary small correction from Table III of the *American Ephemeris*.

TABLE G. — SUMMARY OF CHRONOMETER RATES.

Station.	Interval.	DAILY RATE ON MEAN TIME. (+ losing — gaining.)		DAILY RATE ON SIDEREAL TIME. (+ losing — gaining.)				
		Chronometer number		Chronometer number.				
		1842	177	1842	177	1824	1823	1829
	1896.	s.	s.	s.	s.	s.	s.	s.
Washington . .	June 22–June 26	....	....	....	....	....	....	+2.95
Sydney	July 10–July 11	—0.29	....	+236.26	....	....	+1.59	....
Sydney	July 11–July 12	—0.18	....	+236.37	....	....	+1.66	....
Ashe Inlet . . .	July 25–July 26	+1.01	+4.24	+237.57	+240.81	....	....	....
Umanak . . .	Aug. 8–Aug. 11	+1.48	+4.81	+238.04	+241.38	....	....	....
Umanak . . .	Aug. 11–Aug. 12	+1.53	+4.88	+238.09	+241.45	....	....	....
Niantilik . . .	Sept. 17–Sept. 18	+1.28	....	+237.84	....	....	....	....
Washington . .	Oct. 15–Oct. 16	....	....	....	....	+0.82	+1.74	....
Washington . .	Oct. 16–Oct. 17	....	....	....	....	+0.67	+1.60	....

SECTION 12. *Reduction of Pendulum Observations.* — The total number of seconds between the first and last coincidences in the swing is divided by the approximate number of seconds in a coincidence interval as given by the first and last coincidences observed. Then reversing the process, the total number of seconds (s) is divided by the total number of coincidence intervals, to obtain the average number of seconds in one interval. The uncorrected period (P) is then obtained from the relations $P = \frac{s}{2s - 1}$ or $P = \frac{s}{2s + 1}$ according as the pendulum is slower or faster than the half seconds of the chronometer, or according as a sidereal or mean time chronometer is used. So as to make them comparable at different stations, the observed periods of the pendulums are next reduced to what they would have been under certain standard conditions. These conditions, which are arbitrarily adopted for convenience, are: arc infinitely small, temperature 15° C., pressure 60 mm. of mercury at 0° C., true sidereal time and inflexible support. The corrections to the observed period in seconds are as follows:

$$\text{Arc correction} = -\frac{P\,M}{32}\,\frac{\sin(\phi + \phi')\,\sin(\phi - \phi')}{\log\sin\phi - \log\sin\phi'},$$

where P is period, M is modulus of common logarithmic system, ϕ and ϕ' are initial and final semi-arcs. This is a formula based on theoretical con-

ditions and on the supposition that the arc of oscillation diminishes in geometrical ratio as the time increases in arithmetical ratio. Actual experiment has proved that the dimunition of arc follows this law at least very closely.

Temperature correction $= + 0.00000837\ P\ (15° - T°)$, where P is the period and T the temperature in degrees centigrade. This coefficient was determined experimentally at Washington by swinging the pendulum at different temperatures. The errors of the thermometer used were carefully determined and corrections applied. Where more than two readings were made during a swing, they were weighted according to the intervening intervals.

Pressure correction $= + 0.000000101 \left[60 - \frac{Pr}{1 + .00367\ T°}\right]$, where Pr is observed pressure in millimeters, and $T°$ is temperature in degrees centigrade. This coefficient also was determined experimentally. The expression $\frac{Pr}{1 + .00367\ T°}$ is simply a reduction of the air pressure to a temperature of 0° centigrade.

Rate correction $= + 0.000011574\ R\,P$, where P is period and R is daily rate on sidereal time in seconds (+ if losing, — if gaining). The coefficient is simply the relation of one second to the number of seconds in a day, or $\frac{1}{86400}$.

Flexure correction $= - 0.00000065\ D$, where D is the observed displacement of the knife-edge in microns when force of 1.5 kilogrammes is applied horizontally in the plane of oscillation. This coefficient also was determined experimentally by swinging the pendulums at Washington on supports of different degrees of flexibility. On a very flexible support the simultaneous movement of the heavy metal case was quite plain in the microscope, even when the pendulum was swinging in a small arc.

The periods, having been thus corrected, were next compared to deduce the relation of the force of gravity at the stations. The theoretical length of these pendulums is unknown, and it cannot be computed or measured with any satisfactory degree of accuracy for pendulums of such form. The pendulums were considered to be of the same length, however, at all stations, after applying the corrections above, and to prove their invariability they were swung at the base station at the Coast and Geodetic Survey Office in Washington, before and after this expedition. From the simple law of the pendulum we

have for Washington $P_w = \pi \sqrt{\frac{l}{g_w}}$, and for any other station $P_0 = \pi \sqrt{\frac{l}{g_0}}$, where P is the period, l the length of the corresponding simple pendulum, and g the force of gravity. Squaring and dividing we have $g_0 = \frac{P_w^2}{P_0^2} g_w$. For g_w at Washington the value 980.098 dynes per gramme, force of gravity (= 980.098 centimeters acceleration of gravity, or 32.1554 feet in English measure) has been provisionally adopted. This is based on several absolute determinations, which, however, do not give very accordant results. In fact, relative measurements of gravity can be made with much greater facility and accuracy than absolute determinations, and it is fortunate, therefore, that the uncertainties in the latter have no effect on the value of relative measurements in connection with the question of the figure of the earth, or the condition of the earth's crust. To obtain the corresponding value of g at any other station, it is only necessary to multiply this value of g_w by the ratio of the square of the period at Washington (P_w^2) to the square of the period at the other station (P_0^2). This was done, using the results with each pendulum separately and with the mean of the three pendulums, and taking for Washington the mean of the periods determined before and after the expedition.

Section 13. *Results of Pendulum Observations.* — In Table H are given the details of the observations and reductions. For each swing the average number of seconds in one coincidence interval is given, the average temperature corrected for thermometer errors, the pressure reduced to 0° C., the uncorrected period and the various corrections depending on the correction formulas already given. The final corrected periods are those reduced to the standard conditions, as already explained. In Table I are collected the mean corrected periods for each pendulum and station, and the difference of each pendulum from the mean. These differences are a check on the observations and on the constancy of the pendulums, as theoretically they should be almost constant. The small variations that appear are probably in large part due to diurnal irregularities in the chronometer rates. From these mean periods gravity at the various stations was computed from the relation $g_0 = \frac{P_w^2}{P_0^2} g_w$, gravity at Washington, Coast and

TABLE H. — PENDULUM OBSERVATIONS AND REDUCTIONS.

Swing number.	Pendulum.	Position.	Knife-edge.	Date, 1896.	Coincidence Interval. Chronometer. 1829.		Total Arc. Initial.	Total Arc. Final.	Temperature.	Pressure.
		Washington, D. C.								
					s.		′	′	°C.	mm.
1	A4	R	II	June 22.	292.86	....	53	20	22.63	58
11	A4	R	II	June 26.	294.67	....	56	21	21.41	61
2	A4	D	II	June 23.	292.50	....	55	20	22.65	60
12	A4	D	II	June 26.	294.49	....	55	21	21.38	58
3	A5	R	I	June 23.	366.29	....	53	21	22.78	61
10	A5	R	I	June 25.	369.26	....	55	19	21.55	58
4	A5	D	I	June 23.	366.23	....	52	19	22.53	60
9	A5	D	I	June 25.	369.21	....	53	21	21.75	59
5	A6	R	I	June 24.	387.24	....	52	20	22.33	61
8	A6	R	I	June 25.	389.63	....	53	20	21.83	59
6	A6	D	I	June 24.	387.96	....	52	21	22.18	57
7	A6	D	I	June 24.	389.00	....	53	19	21.98	60
		Sydney, Cape Breton.								
					1842 M. T.	1823 S. T.				
1	A4	R	II	July 11.	372.26	365.65	53	20	17.81	60
2	A4	D	II	July 11.	372.06	366.12	55	22	17.75	60
3	A5	R	I	July 11.	296.20	486.06	52	20	17.90	63
4	A5	D	I	July 11.	295.09	490.75	52	20	17.57	62
5	A6	R	I	July 12.	282.95	528.52	52	20	17.50	62
6	A6	D	I	July 12.	283.62	525.17	52	19	18.10	58
		Ashe Inlet, Hudson Strait.								
1	A4	R	II	July 25.	229.49	226.45	53	19	4.71	60
2	A5	R	I	July 26.	198.49	195.57	53	19	4.87	69
3	A6	R	I	July 26.	192.30	189.92	53	19	4.75	62

TABLE H. — PENDULUM OBSERVATIONS AND REDUCTIONS. — *Continued.*

Swing number.	Period Uncorrected. Chronometer. 1829.		Corrections. (7th decimal place.) Arc.	Temperature.	Pressure.	Rate. 1829.		Flexure.	Period Corrected. Chronometer. 1829.		Mean.
	Washington, D. C.										
	s.								s.	s.	s.
1	.5008551	.....	−8	−320	+2	+171	....	−6	.5008390	....	....
11	8498	.....	−9	−268	−1	+171	....	−6	8385	....	....
2	8562	.....	−9	−321	0	+171	....	−6	8397	....	....
12	8504	.....	−9	−267	+2	+171	....	−6	8395	....	....
3	6834	.....	−8	−326	−1	+171	....	−6	6664	....	....
10	6779	.....	−9	−274	+2	+171	....	−6	6663	....	....
4	6836	.....	−8	−316	0	+171	....	−6	6677	....	....
9	6780	.....	−8	−283	+1	+171	....	−6	6655	....	....
5	6464	.....	−8	−307	−1	+171	....	−6	6313	....	....
8	6424	.....	−8	−286	+1	+171	....	−6	6296	....	....
6	6452	.....	−8	−301	+3	+171	....	−6	6311	....	....
7	6435	.....	−8	−292	0	+171	....	−6	6300	....	....
									.5007121		
	Sydney, Cape Breton.										
	1842.	1823.				1842.	1823.		1842.	1823.	
1	.4993293	.5006846	−8	−117*	0	+13654	+92	−10	.5006812	.5006802	.5006807
2	3290	6838	−9	−115	0	+13654	+92	−10	6810	6796	6803
3	1574	5149	−8	−121	−3	+13649	+92	−10	5081	5099	5090
4	1543	5099	−8	−107*	−2	+13656	+96	−10	5071	5067	5069
5	1181	4735	−8	−104*	−2	+13655	+96	−10	4711	4706	4708
6	1201	4765	−8	−129*	+2	+13655	+96	−10	4711	4715	4713
									.5005533	.5005531	.5005532
	Ashe Inlet, Hudson Strait.										
1	.4989129	.4988984	−8	+430	0	+13719	+13906	−6	.5003262	.5003304	.5003283
2	7436	7249	−8	+423	−9	+13715	+13902	−6	1551	1551	1551
3	7033	6871	−8	+428	−2	+13714	+13901	−6	1159	1184	1172
									.5001991	.5002012	.5002002

* This correction to be increased by one unit (7th decimal place) for chronometer 1,823.

TABLE H. — PENDULUM OBSERVATIONS AND REDUCTIONS. — *Continued.*

Swing number.	Pendulum.	Position.	Knife-edge.	Date, 1896.	Coincidence Interval. Chronometer. 1842 M. T.	Coincidence Interval. Chronometer. 177 M. T.	Total Arc. Initial.	Total Arc. Final.	Temperature.	Pressure.
					s.	s.	° ′	′	°C.	mm.
				Umanak, Greenland.						
1	A4	R	II	Aug. 9.	209.36	207.07	53	19	10.83	61
7	A4	R	II	Aug. 11.	209.48	206.19	53	21	10.15	64
2	A4	D	II	Aug. 9.	211.47	207.99	53	17	11.71	62
8	A4	D	II	Aug. 11.	210.55	206.49	53	19	10.72	59
3	A5	R	I	Aug. 9.	185.13	182.58	53	20	12.41	62
9	A5	R	I	Aug. 11.	184.77	181.58	53	22	11.73	60
4	A5	D	I	Aug. 10.	184.49	181.85	51	19	11.66	66
10	A5	D	I	Aug. 12.	183.76	180.78	51	20	10.86	57
5	A6	R	I	Aug. 10.	178.54	176.16	52	19	10.70	66
11	A6	R	I	Aug. 12.	178.49	176.29	53	19	10.87	62
6	A6	D	I	Aug. 10.	178.40	176.18	55	23	10.57	58
12	A6	D	I	Aug. 12.	178.85	176.77	53	21	11.62	56
				Niantilik Harbor, Cumberland Sound.						
1	A4	R	II	Sept. 17.	218.61	....	53	21	2.01	63
2	A5	R	I	Sept. 18.	189.09	....	53	30	1.22	64
3	A6	R	I	Sept. 18.	185.33	....	52	31	2.58	62
				Washington, D. C.	1823 S. T.	1824 S. T.				
1	A4	R	II	Oct. 15.	299.65	297.69	53	21	16.41	60
2	A4	D	II	Oct. 16.	298.89	297.06	53	21	16.63	59
3	A5	R	I	Oct. 16.	375.33	372.48	53	19	16.93	58
4	A5	D	I	Oct. 16.	376.11	372.95	52	20	16.97	60
5	A6	R	I	Oct. 17.	396.87	393.84	51	19	17.03	60
6	A6	D	I	Oct. 17.	396.02	392.62	53	27	17.15	60

TABLE H. — PENDULUM OBSERVATIONS AND REDUCTIONS. — *Concluded.*

Swing number.	Period Uncorrected.		Corrections. (7th decimal place.)						Period Corrected.		
	Chronometer.					Rate.			Chronometer.		
	1842.	177.	Arc.	Temperature.	Pressure.	1842.	177.	Flexure.	1842	177.	Mean.
	Umanak, Greenland.										
	s.	s.							s.	s.	s.
1	.4988087	.4987957	−8	+174	−1	+13743	+13936	−13	.5001982	.5002045	.5002014
7	8094	7904	−8	+203	−4	+13743	+13936	−13	2015	2018	2016
2	8206	8009	−7	+137	−2	+13743	+13936	−13	2064	2060	2062
8	8155	7922	−8	+179	+1	+13743	+13936	−13	2057	2017	2037
3	6532	6345	−8	+108	−2	+13738	+13931	−13	0355	0361	0358
9	6506	6270	−9	+136	0	+13738	+13931	−13	0358	0315	0336
4	6485	6290	−8	+139	−6	+13738	+13931	−13	0335	0333	0334
10	6432	6209	−8	+173	+3	+13741	+13935	−13	0328	0299	0314
5	6037	5849	−8	+180	−6	+13737	+13930	−13	.4999927	.4999932	.4999930
11	6033	5859	−8	+174	−2	+13740	+13934	−13	9924	9944	9934
6	6026	5850	−9	+185	+2	+13737	+13930	−13	9928	9945	9936
12	6061	5897	−8	+141	+4	+13740	+13934	−13	9925	9955	9940
									.5000766	.5000769	.5000768
	Niantilik Harbor, Cumberland Sound.										
1	.4988590	....	− 8	+542	−3	+13734	....	−6	.5002849	....	....
2	6813	....	−11	+575	−4	+13729	....	−6	1096	....	....
3	6547	....	−11	+518	−2	+13728	....	−6	0774	....	....
									.5001573	....	....
	Washington, D. C.										
	1823.	1824.				1823.	1824.		1823.	1824.	
1	.5008357	.5008412	− 8	−59	0	+101	+48	−6	.5008385	.5008387	.5008386
2	8378	8430	− 8	−68	+1	+101	+48	−6	8398	8397	8398
3	6670	6721	− 8	−81	+2	+101	+48	−6	6678	6676	6677
4	6656	6712	− 8	−83	0	+ 93	+39	−6	6652	6654	6653
5	6307	6356	− 8	−85	0	+ 93	+39	−6	6301	6296	6298
6	6321	6376	−11	−90	0	+ 93	+39	−6	6307	6308	6308
									.5007120	.5007120	.5007120

TABLE I.—Summary of Corrected Periods.

Station.	Date.	Periods.				Differences from mean. (7th decimal place.)		
		Pendulum A4. Knife-edge II.	Pendulum A5. Knife-edge I.	Pendulum A6. Knife-edge I.	Mean of three pendulums.	A4.	A5.	A6.
	1896.	s.	s.	s.	s.			
Washington . . .	June 22–June 24.	.5008392	.5006665	.5006305	.5007121	+1271	−456	−816
Sydney	July 11–July 12.	06805	5080	4710	05532	+1273	−452	−822
Ashe Inlet	July 25–July 26.	03283	1551	1172	02002	+1281	−451	−830
Umanak	Aug. 9–Aug. 12.	02032	0336	.4999935	00768	+1264	−432	−833
Niantilik	Sept. 17–Sept. 18.	02849	1096	.5000774	01573	+1276	−477	−799
Washington . . .	Oct. 15–Oct. 17.	08392	6665	6303	07120	+1272	−455	−817

TABLE J.—Values of g Computed from Each Pendulum.

Station.	g in dynes or centimeters.				Differences from mean. (3d decimal place.)		
	Pendulum A4.	Pendulum A5.	Pendulum A6.	Mean of three pendulums.	A4.	A5.	A6.
Washington. (C. and G. S.)	....	....	....	[980.098]			
Sydney	980.720	980.719	980.722	980.720	0	+1	−2
Ashe Inlet	982.101	982.104	982.110	982.105	+4	+1	−5
Umanak	982.592	982.581	982.597	982.590	−2	+9	−7
Niantilik	982.271	982.282	982.267	982.273	+2	−9	+6

TABLE K. — SUMMARY OF GRAVITY RESULTS WITH REDUCTION TO SEA LEVEL, AND COMPARISON WITH THEORETICAL FORMULA.
(RESULTS FOR g EXPRESSED IN DYNES OR CENTIMETERS.)

Number.	Station.	Latitude. (North.)	Longitude. (West of Greenwich.)	Elevation. H.	Surface density. δ	g observed.	Reduction to Sea Level.			g Reduced to Sea Level.		Theoretical value computed, g_0.	Residuals.	
							Elevation $2g\frac{H}{r}$	Attraction $2g\frac{H}{r}\frac{3\delta}{4\Delta}$	Topographical correction.	Bouguer's formula, g_1.	Attraction term omitted, g_2.		$g_1 - g_0$	$g_2 - g_0$
		° ′ ″	° ′ ″	Meters.										
1	Washington, D.C. (C. & G.S.)	38 53 13	77 00 32	14	2.3	[980.098]	+.004	—.001	.000	980.101	980.102	980.087	+.014	+.015
2	Sydney, Cape Breton . . .	46 08 32	60 11 47	11	2.35	980.720	+.003	—.001	.000	980.722	980.723	980.732	—.010	—.009
3	Ashe Inlet, Hudson Strait . .	62 32 48	70 35 20	15	2.6	982.105*	+.005	—.002	+.001	982.109	982.111	982.104	+.005	+.007
4	Umanak, Greenland	70 40 29	52 08 21	10	2.6	982.590	+.003	—.001	+.002	982.594	982.595	982.632	—.038	—.037
5	Niantilik, Cumberland Sound .	64 53 [30]	66 19 32	7	2.6	982.273*	+.002	—.001	+.001	982.275	982.276	982.271	+.004	+.005

* Approximate results only.

Geodetic Survey Office (g_w) being taken to be 980.098 dynes or centimeters, as already explained. The results for g computed separately for each pendulum and station, with the mean and differences from the mean, are given in Table J. At Ashe Inlet and Niantilik the results can only be considered as approximate because of the failure to obtain sufficient time observations, as referred to under the head of chronometer rates. In Table K is given a general summary of the results, with geographical positions and elevations of stations, estimated surface densities,[1] reduction to sea level, and comparison with a theoretical formula. The reduction to sea level is given by two different methods following the plan adopted in the last report of the International Geodetic Association,[2] first using Bouguer's formula, and second, omitting the attraction term in this formula. Bouguer's formula is $dg = + \frac{2gH}{r}\left(1 - \frac{3\delta}{4\triangle}\right)$, where dg is the correction to observed gravity, g is gravity at sea level, H is elevation above sea level, r is radius of the earth, δ is density of the matter lying above sea level, and $\triangle$ is mean density of the earth. The first term takes account of the distance from the earth's center, and the second term of the vertical attraction of the matter lying between the sea level and station, on the supposition that the latter is located on an indefinitely extended horizontal plain. Wherever the topography about a station departs materially from this condition of a horizontal plain, a third term must be added to the above formula, being a correction to the second term or to observed gravity on account of such irregularities. This is called the topographical correction, and will always be positive, as the effect of all deviations from the horizontal plain, whether hills or mountains rising above the station, or valleys or canyons lying below it, will be to diminish the force of gravity.[3] This correction is not important at any of these stations, but has been approximately

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[1] These estimates of the average density or specific gravity of the masses above sea level underlying the respective stations have been furnished by Mr. G. K. Gilbert, of the U. S. Geological Survey. The character of the rocks is as follows: Sydney, sandstone, shale; Ashe Inlet, gneiss; Umanak, gneiss; Niantilik, gneiss; Washington, sand and clay.

[2] "Bericht über die relativen Messungen der Schwerkraft mit Pendelapparaten, von Professor Helmert," Verhandlungen der elften Conferenz der Internationalen Erdmessung, Berlin, 1895.

[3] For formulas for this correction see Report U. S. Coast and Geodetic Survey for 1894. App. 1, pages 22 and 23.

estimated from the very scanty knowledge of the surrounding topography for those stations where it is thought to be appreciable.

Although the attraction of the mass above sea level at any station must be a real quantity, yet the omission of this correction, the second term of Bouguer's formula, has been advocated on the basis of certain theories of the condition of the earth's crust, as for instance, that it is in a state analogous to hydrostatic equilibrium, and hence that all elevations are compensated by deficiencies in density beneath, and the results of the pendulum observations themselves have in general, though not in particular, tended to confirm this position. This question will be referred to again. Various other methods of reduction have been proposed. As has been remarked by Professor Helmert, the reduction to sea level will also depend on the application to be made of the results. If they are to be used in connection with the problem of the figure of the earth, the normal force of gravity at the sea level will be required; if, however, it is desired to study the irregularities in density below sea level, it seems quite proper that the real attraction of the mass above sea level as represented by the second term of Bouguer's formula should be subtracted. These different methods of reduction need not be considered as necessarily conflicting, therefore, as might appear at first sight.

The values reduced to sea level in Table K are next compared with an assumed theoretical formula $g = 978.066\ (1 + .005243 \sin^2 \text{latitude})$ which is based on Clairaut's theorem, Clarke's figure of the earth (1880), and the assumption that gravity is normal on the eastern coast of the United States; the values of g by this formula being computed for the latitude of each of the stations.[1] Such comparisons are useful in showing the differences between the observed results and those based upon values for the flattening of the earth derived from other sources, and to develop the local anomalies in the force of gravity. The results of this season can be added to the constantly accumulating store of information to be used in future discussions of pen-

[1] The most generally used theoretical formula for the variation of the force of gravity with latitude is that derived by Professor Helmert from an elaborate discussion of pendulum observations in various parts of the world, $g = 978.000\ (1 + .005310 \sin^2 \text{latitude})$ centimeters, which corresponds to the value $\frac{1}{299.3}$ for the flattening of the earth. "Die mathematischen und physikalischen Theorien der höheren Godäsie," Vol. II, p. 241. This discussion was made in 1884, and is based on pendulum observations at 122 stations, which is but a small proportion of the data that is now available.

dulum observations either with respect to the figure of the earth or otherwise. Their principal value will be in their combination with results in other parts of the world.

The possibility of an interesting application of pendulum observations suggested itself to the writer in connection with future exploration in Greenland. The remarkable ice cap covering this great island rises to an elevation of about 10,000 feet (3,000 meters), but what proportion of this elevation is ice and what land, is an unsolved and most interesting problem. It is very probable that a comparison of pendulum observations on the bare coast with others on the ice cap would throw considerable light on the subject, although it might not settle the question definitely.

Section 14. *Comparison of Periods at Washington.* — The constancy of the periods of pendulums being a most important matter in connection with the use of those of the so-called invariable type in relative measurements of the force of gravity, it is of interest to compare the periods of these three pendulums as given by various determinations at the base station at Washington during the past three years. Table L gives the corrected periods at Washington resulting from ten determinations from April, 1894, to October, 1896. The values for 1894 differ slightly from those previously published, because in order to render them strictly comparable with the later results, a correction of $^{s}.0000013$ was subtracted from the period of $A4$ to allow for the fact that it was swung on a different knife-edge, and a correction of $^{s}.0000003$ was added to the periods of all three pendulums to allow for improved values in the thermometer corrections. The total range in the mean period of the three pendulums for these ten determinations is only $^{s}.0000008$, and the means for the separate years differ by only $^{s}.0000001$. When it is considered that these pendulums during this interval of two and one-half years have been swung at fifty stations (including Washington) and have been transported many thousand miles by rail and ship, the permanency of period is certainly satisfactory.

TABLE L. — SUMMARY OF PERIODS AT WASHINGTON.

Number.	Date.	Approximate average temperature.	Corrected Periods.				Differences from Mean. (7th decimal place.)		
			Pendulum A4.	Pendulum A5.	Pendulum A6.	Mean of three pendulums.	A4.	A5.	A6.
	1894.	°C.	s.	s.	s.	s.			
1	Apr. 25–Apr. 27.	16	.5008396	.5006665	.5006303	.5007122	1274	457	819
2	May 10–May 12.	19	8394	6669	6307	7123	1271	454	816
3	May 31–June 2.	17	8398	6667	6305	7123	1275	456	818
4	June 23–June 25.	23	8398	6665	6305	7123	1275	458	818
5	Oct. 31–Nov. 2.	17	8390	6659	6309	7120	1270	461	811
					Mean for 1894.	7122			
	1895.								
6	Jan. 11–Jan. 13.	11	8396	6681	6298	7125	1271	444	827
7	Aug. 2–Aug. 4.	21	8380	6662	6310	7117	1263	455	807
					Mean for 1895.	7121			
	1896.								
8	Jan. 21–Jan. 23.	11	8383	6668	6315	7122	1261	454	807
9	June 22–June 24.	22	8392	6665	6305	7121	1271	456	816
10	Oct. 15–Oct. 17.	17	8392	6665	6303	7120	1272	455	817
					Mean for 1896.	7121			

SECTION 15. *Notes on the Historical Development of Pendulum Apparatus.*[1] — The laws of the motion of a pendulum were first announced by Galileo in 1629. It is a disputed question as to whom belongs the honor of the discovery of isochronism, that important property of the pendulum by which it oscillates in different small arcs in nearly equal times, though tradition attributes this to Galileo, who is said at the age of twenty to have noticed the isochronism in the swinging of a chandelier in a church at Florence. This property appears to have been known as early as 1589, which epoch may be taken as the beginning of the history of the pendulum. In 1641, a year before his death, Galileo had conceived the idea of the applica-

[1] The historical data in this and the following section are taken largely from "Collection de Mémoires relatifs a la Physique publiés par la Société Francaise de Physique, Tome IV. Mémoires sur le Pendule" (Introduction Historique, C. Wolf); also "Account of the Operations of the Great Trigonometrical Survey of India," Vol. V, "The Pendulum Operations" (Appendix, "Notes for a history of the use of invariable pendulums"); also Verhandlungen der siebenten Conferenz der Europaischen Gradmessung," Rome, 1883, "Rapport sur la détermination de la pesantéur a l'aide de différents appareils, par M. Theodore von Oppolzer."

tion of the pendulum to clocks for time-keeping purposes, but he did not develop nor publish it. The Dutch philosopher Huyghens made known and patented a pendulum clock in 1657, and thus appears to be entitled to the honor of the first practical application of the pendulum for this purpose. Huyghens also did much towards developing the mathematical theory of the pendulum. In 1644 Mersenne made the first determination of the length of the seconds pendulum. The effect of changes of temperature on the period of a pendulum was noted by Picard in 1669, and the resistance of the air to the motion was first studied by Newton in 1686. In 1735 Mairan first employed the method of coincidences in determining the period of a pendulum, noting the times when the clock and pendulum were together at the extremity of the arc instead of when they pass through the vertical together, as was the later method. The correction to pendulum observations on account of loss of weight because of being in air, was first applied by Bouguer in 1749, to whom also is due the reduction to sea level known by his name. Boscovich, in 1785, first proposed the second atmospheric correction due to the retardation of the pendulum because of the air dragged with it, and also gave the theory of the ball and wire pendulum, but made no application of it. In response to the request of the Commission of Weights and Measures, Borda in 1792, at the Observatory of Paris, made elaborate observations with the ball and wire pendulum, introducing all the improvements that had been suggested up to that time. The Academy of Sciences had decided that the length of the pendulum beating seconds at Paris should be determined at the same time with the other measurements necessary to the establishment of the metric system. In 1792 Prony proposed a rigid pendulum with three parallel axes in same plane as center of gravity of the pendulum. In 1798 he proposed the pendulum now known as the reversible, but did not construct one. In 1817, without knowledge of Prony's work, Captain Kater, charged by the Committee of Weights and Measures of the Royal Society of London to measure the length of the seconds pendulum, developed his method and constructed the pendulum known by his name, a reversible pendulum with movable weights, and hence called convertible. The theory of the reduction to a vacuum, and of the effect of air on a pendulum, has been studied elaborately by Bessel, Buat, Poisson, and Stokes. Laplace in 1816 first called attention to the influence that the form of the knife-edge would have on the true length of the pen-

dulum. On account of the complicated atmospheric effects, and the uncertainty of the knife-edge, Bessel concluded that it was impossible to accurately measure the length of the seconds pendulum by means of the simple ball and wire. Because of its lack of symmetry Kater's pendulum also failed to eliminate the atmospheric effects. In 1827 Bessel elaborated the conditions necessary for the reversible pendulum, the most important being the external symmetry of the two ends of the pendulum, but an instrument following these ideas was employed for the first time by Plantamour in 1866, as constructed by Repsold. Various modifications of this type of pendulum have been widely used since that time, more particularly in absolute measurements of the force of gravity. In his well-known experiments at Königsberg in 1826, Bessel first introduced a differential method in determining the length of the seconds pendulum; a ball and wire pendulum was used, the length of the wire being varied by an amount exactly equal to a standard toise. Only the difference of the length of the two pendulums was required, and the differential method was supposed to eliminate many of the constant errors in the effect of the suspension and otherwise. Although this source of error had previously been suspected, Peirce in 1875 first proved that the time of oscillation of a pendulum was affected by the flexibility of its support, and he investigated this question both experimentally and mathematically. About 1887, Defforges introduced in the "Service Geographique" of France a differential method of determining the absolute force of gravity, using two symmetrical reversible pendulums of the same weight but of different lengths, with interchangeable knife-edges.

The variation of the rate of clocks, when transported from place to place, early suggested the use of the invariable pendulum to measure the relation of the force of gravity at different points. The first instrument designed for this purpose seems to have been that of Graham, a celebrated clock maker of London, who in 1731 used an invariable pendulum connected with wheel work arranged to register the number of oscillations. This was rated in London and in the island of Jamaica. This instrument was used by Sabine as late as 1820, although it was unsatisfactory on account of the variable effect of the wheel work on the pendulum. Bouguer and LaCondamine used an entirely free invariable pendulum of such mass that it would oscillate an entire day, on the expedition of 1735 to 1743 to measure the Peruvian arc. Malaspina, on a Spanish expedition from 1789 to

1794, employed a pendulum having a wooden rod, steel knife-edge and copper lenticular bob. About 1817 Kater constructed an invariable pendulum which he used at various stations of the Ordnance Survey in England. Many copies of this pendulum were made, some of which were employed at wide intervals of time and up to a very recent date. They are simple in design, consisting of a flat brass bar over five feet in length, having a large flat circular brass bob and a hard steel knife-edge. A radical change in invariable pendulums was introduced in 1882, when Von Sterneck employed a half second pendulum in Austria, together with an elegant electrical arrangement for observing coincidences between a clock or chronometer and a pendulum. When it is considered that a half second pendulum is only about one-fourth the length of a seconds pendulum (which was previously the almost universal length) and that the older methods of observing coincidences could not be used with a chronometer, the important effect of this step on the facility of gravity research may be realized. In 1890 a form of half second pendulum apparatus, differing in important respects from that of Von Sterneck, was designed by Mendenhall, who also in 1894 designed a quarter second pendulum apparatus, the most portable instruments of the kind yet constructed, the air-tight case in which the pendulums are swung being only 17 cm. (6.7 inches) high. A pendulum which is called "reversible inversible" was designed by Defforges and first used in 1890. It is a symmetrical reversible pendulum about a half meter in length and is provided with interchangeable knife-edges and weights.

Section 16. *Notes on the Progress of Research in Terrestrial Gravity Measurements.* — To obtain some instrument with which the force of gravity could be more conveniently and simply measured than with the pendulum, has been a problem that has long engaged the attention of physicists, and was considered of sufficient importance for the appointment of a special committee by the British Association for the Advancement of Science a few years ago. Various devices depending principally on the compressibility of gases, and the elasticity of metals, have been proposed from time to time, but nothing has yet been found to give sufficiently reliable results. Pendulums as they have been used in gravimetric research may be divided into three general classes: the ball and wire, the reversible and the invariable. The ideal simple pendulum to which the law $t = \pi \sqrt{\frac{l}{g}}$ applies consists

of a weight concentrated at a single point and suspended from its center of oscillation by a weightless thread. The nearest approach to this possible in practice is the ball and wire pendulum, which in early days was much used, but which was an instrument only suited for laboratory experiments, and even then was subject to serious difficulties in eliminating various sources of error. With this instrument the moments of inertia of the various parts must be considered in computing the length of the pendulum. The reversible pendulum, which has been very generally used in modern absolute measurements of the force of gravity, depends on the principle that in any compound or material pendulum swung from a point which may be called the center of suspension, there is a reciprocal point situated on a line passing through the center of gravity, called the center of oscillation, about which the period of the pendulum will be the same if it is reversed; and further, that the period of the compound pendulum will be the same as that of a simple pendulum of length equal to the distance between the center of suspension and the center of oscillation, and known as the equivalent simple pendulum. This principle was first applied by Kater in his convertible pendulum, an unsymmetrical pendulum with movable weights, so that the center of gravity could be shifted until the condition of equal periods about the two knife-edges was obtained. Following Bessel's idea, the reversible pendulum as used in recent years has had a symmetrical form and fixed center of gravity, but with one end heavy and the other light. It is so designed that the periods of oscillation shall be approximately equal about the two knife-edges. When this condition is reached, the period of the equivalent simple pendulum is given by the relation $T^2 = \frac{h t^2 - h' t'^2}{h - h'}$, where t and t' are the times of oscillation about the knife-edges, whose distances from the center of gravity are respectively h and h'; g may be determined from this relation (remembering that $h + h'$ is the length of the equivalent simple pendulum whose period is T) when the periods in the two positions are ascertained, and the distance between knife-edges, and the approximate distance from each knife-edge to the center of gravity. The determination of the absolute force of gravity is an operation of more importance to physics in general than to geodesy. Nevertheless, in order to be able to express results in absolute measure, a number of such determinations have been made in connection with geodetic operations. The following table (M) gives some of the more

important determinations made either in this connection or otherwise, with results referred to Washington by means of relative connections that have been made.[1] Some of these results are now principally interesting from an historical point of view. Even the determinations apparently the most reliable do not show a satisfactory accordance.

TABLE M. — ABSOLUTE DETERMINATIONS OF THE FORCE OF GRAVITY, WITH RESULTS REDUCED TO WASHINGTON, C. AND G. S. OFFICE (NOT REDUCED TO SEA LEVEL).

Number.	Observer.	Date.	Place of determination.	Apparatus.	Results reduced to Washington, Coast and Geodetic Survey Office.	
					Length sec. pendulum.	Gravity.
					cm.	Dynes or cm.
1	Borda . .	1792.	Paris . . .	Ball and wire	99.3102	980.153
2	Kater . .	1817.	London . .	Kater convertible pendulum	.3236	.285
3	Bessel . .	1826–27.	Königsberg,	Ball and wire, 2 lengths, differential .	.3021	.072
4	Sabine . .	1829.	Greenwich .	Kater convertible pendulum	.3005	.056
5	Plantamour,	1865–71.	Geneva . .	Bessel reversible pendulum	.3028	.079
6	Peirce . .	1876.	Paris . . .	Bessel reversible pendulum	.3109	.159
7	Von Orff .	1877.	Munich . .	Repsold reversible pendulum	.3088	.138
8	Mendenhall,	1880.	Tokio . .	Ball and wire	.3114	.164
9	Oppolzer .	1884.	Vienna . .	Repsold reversible pendulum	.3085	.135
10	Lorenzoni .	1886.	Padua . .	Repsold reversible pendulum	.3007	.058
11	Defforges .	1893.	Washington,	Two reversible pendulums, differential,	.3115	.165

In the study of the variations of gravity over the earth's surface, with which geodesy and terrestrial physics are principally concerned, the invariable pendulum has been largely used and appears to be the most convenient form on account of its greater simplicity both in its construction and manipulation. The development of this instrument and its various types has already been referred to. Reversible pendulums have also been used to a considerable extent in this connection, and even the ball and wire pendulum was so employed in the earlier work. The first experimental proof of the variations of gravity with latitude was furnished by the famous observation of Richer, who in 1672 measured the length of a seconds pendulum at Cayenne near the equator, and found that it was $1\frac{1}{4}$ line (= 2.8 mm.), or about the $\frac{1}{860}$ th part shorter there than at Paris. Many astronomers attributed

[1] For a more complete list see App. No. 1, Report U. S. C. and G. Survey for 1894, p. 48.

this difference simply to the effect of the warmer climate on the iron standard of length, but its reality was soon confirmed by observations made in other parts of the world under the auspices of the French Academy, as well as by the theories of Newton, published in 1687, as to the flattening of the earth at the poles. In 1743 Clairaut published his famous theorem establishing a relation between the force of gravity and the flattening of the earth, which may be stated as follows: $\frac{a-b}{a} = \frac{5}{2}\frac{c}{g_\varepsilon} - \frac{g_\phi - g_\varepsilon}{g_\varepsilon}$ where a and b are the equatorial and polar semi-diameters of the earth, g_ϕ and g_ε are the polar and equatorial forces of gravity, and c is the centrifugal force at the equator.[1] "In his demonstration, Clairaut makes no assumption of original fluidity; he supposes the strata to be concentric and coaxal spheroidal shells, the density varying from stratum to stratum in any manner whatever; it is assumed however that the superficial stratum has the same form as if it were fluid, and in relative equilibrium when rotating with uniform angular velocity. Professor Stokes in his demonstration of Clairaut's Theorem, in two papers published in 1849, showed that if the surface be a spheroid of equilibrium of small ellipticity, Clairaut's Theorem follows independently of the adoption of the hypothesis of original fluidity or even of that of any internal arrangement in nearly spherical strata of uniform density."[2] In the early part of this century a number of expeditions were sent out partly or wholly for the purpose of making pendulum observations, among the more important of which may be noted those of Kater, 1818–19; Sabine, 1819–24; Foster, 1828–31; Lütke, 1826–29; Freycinct, 1817–20; Duperrey, 1822–25, and Biot and Mathieu, 1808–24. With the methods then in use, however, but a comparatively small number of points could be determined, and these were almost entirely confined to the sea coast. The subject was then almost entirely neglected until 1864, when, in connection with the Great Trigonometrical Survey of India, an extensive series of pendulum observations, without precedent up to that time, was undertaken and carried out, yielding most interesting results. Since that time this subject has been taken up by various countries engaged in geodetic operations, and has been included in the scope of the investigations of the International Geodetic Association. In the reports of this Association the results are systematic-

[1] A more rigid expression for this formula is given by Helmert, Geodäsie, Vol. II, p. 83.
[2] Clarke's Geodesy, p. 82.

ally collected and published from time to time. Professor Helmert's elaborate report on the subject at the meeting of the Association in Berlin, in 1895, included 968 such measurements, more than a third of which, however, were in a single country (Austria).

The flattening of the earth cannot be computed from Clairaut's Theorem directly, because thus far it has been impracticable to measure the force of gravity at the poles. But it has been demonstrated that the increase of gravity from the equator to the poles will be as the square of the sine of the latitude, or $g_0 = g_\varepsilon \left(1 + \frac{g_\varepsilon - g_p}{g_\varepsilon} \sin^2 \phi_0\right)$ where g_0 is gravity at any latitude ϕ_0, g_ε at the equator and g_p at the poles. With this expression g_ε and g_p may be derived from determinations of g made at two or more different latitudes. Substituting in Clairaut's Theorem, the amount of the flattening can then be computed. As material has accumulated from time to time, a number of such deductions have been made by combining all available pendulum observations. Some of these are as follows:

From a table by Professor Harkness, Report C. and G. Survey for 1893, Part II, p. 250.

Date.	Authority.	Flattening $= \frac{a-b}{a}$
1799.	Laplace.	335.8
1825.	Sabine.	289.1
1830.	Airy.	282.8
1834.	Baily.	285.3
1880.	Clarke.	292.2
1884.	Helmert.	299.3

The two most important values of the flattening of the earth derived from the entirely independent method of arc measurements, are those of Bessel (1841) $\frac{1}{299.2}$, and Clarke (1880) $\frac{1}{293.5}$. The pendulum observations, of course, furnish information only as to the ratio of the axes and not as to their absolute lengths, which are furnished by arc measurements. The flattening as deduced by either method is subject to uncertainties because of the irregularities in the earth's surface, both in density and shape and the necessary confinement of measurements to land areas, but the pendulum observations have the advantage of the possibility of extension to regions that can never be reached by triangulation.

Early in the discussion of pendulum observations it became apparent that the force of gravity over the earth's surface did not always

follow Clairaut's law when the reduction to sea level was made by Bouguer's formula, or the attraction of the mass above sea level was subtracted. As early as 1830 Airy pointed out the fact that gravity seemed to be greater on oceanic islands than on continents in corresponding latitudes, and the accumulation of later data has clearly brought out the fact that with Bouguer's reduction there is apparently an excess of gravity of about $\frac{1}{4000}$th part on oceanic islands as compared with continental coasts, and a defect of similar amount beneath elevated continental masses. Two causes might lead to such a condition: first, the sea level may be distorted, raised above the mean figure of the earth under continents, and lowered below in ocean centers, and thus points at sea level under continents would be at a greater distance from the earth's center than at oceanic islands; or second, the earth's crust may be less dense below continents than under the oceans. On the theory that the crust of the earth is in a condition analogous to hydrostatic equilibrium, which was first proposed by Airy in 1855, it has been computed that the distortion of the sea level would not be over about 10 feet (3 meters). This theory appears to be the favorite one, and based on it the differences between normal and observed gravity, using Bouguer's reduction, have been taken as a measure of the excess or deficiency in density beneath the sea level. In discussions of the figure of the earth from pendulum observations various methods have been proposed of eliminating these local peculiarities. Thus it has been proposed in the reduction to sea level to omit the correction for the attraction of the mass above sea level, for the reason that on the equilibrium theory that mass must be compensated by a deficiency of density beneath. This would not help matters much in the case of oceanic island observations, however, where the stations are often close to sea level. Faye in 1880 suggested that while in general the equilibrium condition might be true, it could scarcely apply to limited areas on the earth's surface; as, for instance, that a large plateau might be supported in a condition of equilibrium, whereas a mountain on that plateau would be supported by the partial rigidity of the crust, and he therefore proposed that in the reduction of pendulum observations to sea level the attraction of average areas should be considered as probably compensated by deficiency or excess of density beneath, but that the local departures from that average area should be allowed for. A rough application of this idea to a number of observations made in this country in 1894, and in other parts of the world previously, showed that the results gave far greater

accordance on this supposition than on any other. A striking illustration of this was Pike's Peak, which is a comparatively isolated mountain rising about 2,450 meters above a plateau whose elevation is about 1,840 meters above sea level. When the attraction of the entire mass above sea level was subtracted, the observed force of gravity appeared to be about $\frac{1}{4000}$th part below normal, but when no correction for this attraction was applied, gravity appeared about the same amount above normal. When, however, only the attraction of the peak itself as it stood above the average elevation of the country was allowed for, the result appears quite normal. The result obtained at the celebrated station Moré in the Indian series, at an elevation of 15,408 feet (4,696 meters) in the Himalayan mountains, is not discordant with this idea. Here it was found that the defect of gravity with Bouguer's reduction to sea level was closely equal to the correction for the attraction of the mass above sea level, but Moré is situated in a valley and is shown to have been nearly at the average elevation of the surrounding region.

The connection between variations in the force of gravity and deflections of the plumb line was brought out in an interesting manner in the Indian series. As the triangulation approached the Himalayas the deflection towards this mountain mass was found to be less than had been estimated, a fact that was explained when the pendulum observations indicated a deficiency of density beneath. Quite recently such a relation has been brought out in a striking manner by a series of gravity measurements made along a meridian line in Germany, at points where the plumb line deflections had been obtained by a comparison of astronomical latitude observations with geodetically determined positions. In Professor Helmert's discussion of this work, he shows that plumb line deflections, in a region where they would not be accounted for by the apparent surface conditions, have a distinct relation to irregularities in density beneath, as developed by the pendulum.[1]

Another application of pendulum gravity measurements has been in the determination of the mean density of the earth. By comparing the measured force of gravity at the ordinary surface with that at the summit of a mountain or the bottom of a mine, it is possible to compute the ratio of the mean density of the earth to the density of the

[1] "Ergebnisse von Messungen der Intensität der Schwerkraft auf der Linie Kolberg-Schneekoppe, von F. R. Helmert." Sitzungsberichte der Königlich Preussischen Akademie der Wissenschaften zu Berlin. XVIII. 1896.

mountain or the mass between the bottom and top of the mine, which latter may be estimated from determinations of the specific gravity of surface specimens. Because of various practical difficulties this method cannot compete with refined laboratory methods of recent times, and is likely to prove more valuable when reversed, that is, in the investigation of the mean densities of mountains. Some of the determinations made by pendulum observations are as follows:

Date.	Observer.	Place.	Mean density of the earth.
1821.	Carlini.	Mount Cenis, Alps.	4.95
1854.	Airy.	Harton Pit (mine), England.	6.56
1880.	Mendenhall.	Fujiyama, Japan.	5.77
1883.	Von Sterneck.	Pribram (mine), Bohemia.	5.77
1892.	Preston.	Mauna Kea, Hawaiian Islands.	5.13
1894.	Putnam.	Pike's Peak, United States.	5.63

Part IV. Examples of Observations.

Section 17. *Latitude Observations at Umanak, Greenland.* — These observations were made by Talcott's method[1] with meridian telescope No. 13, used as a zenith telescope. The method depends on the micrometric measurement of the difference of zenith distance of two stars crossing the meridian at nearly equal distances, one north and one south of the zenith, and at a short interval of time. It is evident that the mean of the declinations of two stars which crossed the meridian at exactly equal zenith distances north and south, would be the latitude of the place, and with this method it is only necessary to determine a correction to the mean declinations to allow for the fact that the zenith distances are not exactly equal. The strong point of the method lies in the fact that it is free from circle readings, depending only on the micrometer, a delicate level, and the computed declinations of the stars.

For this latitude only three pairs of stars (as given below) were observed on two nights. The right ascensions and declinations given are the mean places for 1896.0, computed from the Greenwich (1880), Safford's, and the Pulkowa catalogues. The second star in each of these pairs was observed at lower culmination.

[1] For explanations of this method and of the instruments used, see Report U. S. C. and G. Survey for 1880, App. 14; also Chauvenet's Astronomy, Vol. II, p. 340; also Doolittle's Practical Astronomy, p. 478.

Star Number. B. A. C. catalogue.	Magnitude.	Right ascension.	Declination.	Approximate zenith distance for setting telescope.
		h. m. s.	° ′ ″	° ′
7143	5.1	20 34 00.03	+23 45 03.47	46 55 S.
2982	5.6	8 44 48.35	+62 21 03.52	46 58 N.
7258	6.5	20 50 41.29	+13 19 29.48	57 21 S.
3106	4.4	9 01 32.17	+52 01 26.91	57 18 N.
7402	5.6	21 14 34.37	+43 30 29.28	27 10 S.
3199	4.6	9 22 15.38	+81 47 09.14	27 32 N.

The apparent declinations of the stars for the date of observation were computed by the independent star numbers, by the formula (see American Ephemeris, Part II), $\delta = \delta_0 + \tau\mu' + g\cos(G + a_0) + h\cos(H + a_0)\sin\delta_0 + i\cos\delta_0$, where a_0, δ_0 are the star's mean right ascension and declination at the beginning of the year, τ is the fraction of a year from January 1, μ' is the annual proper motion in declination, and g, G, h, H, and i are factors given in the Ephemeris for each day in the year.

The formula for the latitude, when the observations are made in the meridian, is: $\phi = \frac{1}{2}(\delta + \delta') + \frac{1}{2}(M - M')R + \frac{b}{4}[(n + n') - (s + s')] + \frac{1}{2}(r - r')$ where δ and δ' are the declinations and M and M' the micrometer readings of the south and north stars respectively, R the value in arc of one division of the micrometer, n and s the north and south readings of the level for the south star, and n' and s' the same for the north star, b the value in arc of one division of the level, and r and r' the refraction corrections for the south and north stars. The value of one division of the latitude level was $2''.23$ ($= b$). The value of one turn (100 divisions) of the micrometer was determined at Umanak on August 12, 1896, by observing Polaris near eastern elongation, setting the micrometer thread at each even turn, and noting the time of transit of Polaris;[1] giving the result 1 turn $= 79''.647$. Table N gives a summary of the observations and reductions. The resulting value for the latitude of the meridian telescope is 70° 40′ 29″.2 N., from which the latitude of the magnetic station (12 meters south) is 70° 40′ 28″.8 N., and of the flagstaff (50 meters south) is 70° 40′ 27″.6 N.

[1] For explanation and example, see Report C. and G. Survey for 1880, App. 14, pages 51 and 58.

TABLE N.—Latitude Observations at Umanak.

Date.	Catalogue. B. A. C.		Micrometer.		Level.			Declination.	Sum and Half Sum.	Corrections.			Latitude.
	Star No.	N. S.	Reading.	Diff. Z. D.	N.	S.	Diff. N—S.			Microm.	Level.	Refr.	
			t. d.	t. d.				° ′ ″	° ′ ″	′ ″	″	″	° ″
Aug. 11, 1896.	7143	S	20 90.5		5.0	7.9		23 45 14.72	141 24 15.36				
	2982	N	23 36.5	— 2 46.0	8.6	4.5	+1.2	117 39 00.64	70 42 07.68	— 1 37.97	+0.67	—.06	70 40 30.32
Aug. 12, 1896.	7143	S	20 60.5		4.9	8.4		23 45 14 95	141 24 15.84				
	2982	N	23 06.5	— 2 46.0	8.4	4.9	0.0	117 39 00.89	70 42 07.92	— 1 37.97	0.00	—.06	29.89
Aug. 11, 1896.	7258	S	21 22.3		3.4	9.8		13 19 41.54	141 18 17.82				
	3106	N	19 16.4	+ 2 05.9	9.1	4.1	—1.4	127 58 36.28	70 39 08.91	+ 1 22.00	—0.78	+.08	30.21
Aug. 12, 1896.	7258	S	21 81.0		4.3	9.0		13 19 41.72	141 18 18.22				
	3106	N	19 76.8	+ 2 04.2	7.1	6.1	—3.7	127 58 36.50	70 39 09.11	+ 1 21.32	—2.07	+.08	28.44
Aug. 11, 1896.	7402	S	12 38.0		2.9	10.5		43 30 40.92	141 43 37.83				
	3199	N	29 44.8	—17 06.8	10.9	2.5	+0.8	98 12 56.91	70 51 48.92	—11 19.72	+0.45	—.25	29.40
Aug. 12, 1896.	7402	S	12 83.5		4.3	9.1		43 30 41.23	141 43 38.48				
	3199	N	29 94.3	—17 10.8	8.7	4.8	—0.9	98 12 57.25	70 51 49.24	—11 21.31	—0 50	—.25	27.18
												Mean.	70 40 29.24

SECTION 18. *Example of Computation of Longitudes from Chronometer 1823 (sidereal).*

Station.	Date. (Civil local.)	Epoch Greenwich sidereal time.	Observed corrections on local sidereal time.	Corrections on Greenwich sidereal time.	Average rate per day on sidereal time. (+ losing.)	Corrections on Greenwich sidereal time computed from traveling rate.	Longitude west of Greenwich.
	1896.	h. m.	h. m. s.	s.	s.	m. s.	h. m. s.
Sydney †	July 10.	22 36	−4 00 52.30	−05.23	....	....	.....
Sydney	July 11.	21 08	−4 00 50.81	−03.74	+1.62	....	.....
Sydney	July 12.	21 08	−4 00 49.15	−02.08	....	....	.....
Sydney	July 16.*	12 00	.....	[+03.78]	....	....	.....
Turnavik	July 20.	13 43	−3 57 08.20	.....	....	+0 14.0	3 57 22.2
Ashe Inlet	July 25.	24 01	−4 41 54.90	.....	....	+0 27.6	4 42 22.5
Godhavn	Aug. 3.	8 08	−3 33 16.20	.....	....	+0 48.6	3 34 04.8
Umanak	Aug. 5.*	12 00	[−3 27 40.04]	.....	....	+0 54.0	3 28 34.0
Umanak	Aug. 7.	24 48	−3 27 34.25	.....	....	....	.....
Umanak	Aug. 8.	24 31	−3 27 31.64	.....	....	....	.....
Umanak	Aug. 11.	23 23	−3 27 25.65	.....	+2.29	....	.....
Umanak	Aug. 12.	23 23	−3 27 23.30	.....	....	....	.....
Umanak	Aug. 20.	23 16	−3 27 04.65	.....	....	....	.....
Umanak	Sept. 9.*	24 00	[−3 26 18.78]	.....	....	+2 15.3	3 28 34.1
Niantilik	Sept. 18.	16 40	−4 22 40.5	.....	....	+2 37.1	4 25 17.6
Sydney	Sept. 26.	4 36	−3 57 46.8	.....	....	+2 56.0	4 00 42.8
Washington (C. and G. S.),†	Oct. 3.*	12 00	.....	[+3 14.28]	....	....	.....
Washington	Oct. 6.	1 40	−5 04 41.04	+3 21.10	....	....	.....
Washington	Oct. 15.	4 45	−5 04 23.19	+3 38.95	+1.91	....	. ....
Washington	Oct. 16.	5 22	−5 04 21.40	+3 40.74		....	.....
Washington	Oct. 17.	2 14	−5 04 20.01	+3 42.13	....	....	.....

The traveling rate used in the above is deduced as follows:

		h.	m. s.
Correction at Washington on Greenwich sidereal time	October 3, at 12.0		+3 14.28
Correction at Sydney on Greenwich sidereal time	July 16, at 12.0		+0 03.78
Loss in	79.0 days		+3 10.50
Loss at Umanak in	35.5 days		+1 21.26
Traveling on ship,	43.5 days		+1 49.24
Traveling rate per day			+2.51

*These are dates of arrival and departure (on which no time observations were made), and the chronometer correction is carried out to these dates for each station by using the average rate at that station.

† The adopted longitude of the transit at Sydney was 4 h. 00 m. 47.07 s., and at Washington 5 h. 08 m. 02.14 s.

SECTION 19. *Example of Observations of Sun for Azimuth of Mark and for Time, with Computations.* — Niantilik, Cumberland Sound, September 18, 1896, P.M. Instrument, Theodolite Magnetometer, No. 19.

Object.	Position of instrument.	Time. Chronometer, 1842.	Horizontal Circle.			Vertical Circle.		
			A.	B.	Mean.	A.	B.	Mean.
		h. m. s.	° ′	′	′	° ′	′	′
Azimuth mark	D	.....	53 58	59	58.5	....	..	....
	R	.....	233 55	55	55.0	....	..	....
Means	....	.....	53	..	56.8	....	..	...
Sun's first and upper limb	R	7 39 20	229 46	44	45.0	17 17	18	17.5
	....	40 40	230 05	03	04.0	11	13	12.0
	....	41 34	19	16	17.5	06	09	07.5
Sun's second and lower limb	D	42 58	51 16	17	16.5	73 33	33	33.0
	....	44 04	33	33	33.0	39	39	39.0
	....	45 33	54	55	54.5	46	47	46.5
Means	....	7 42 21.5	50	..	48.4	16	..	46.4
Sun's second and lower limb	D	7 46 34	52 09	09	09.0	73 50	51	50.5
	....	47 33	23	24	23.5	55	57	56.0
	....	48 31	38	38	38.0	74 02	03	02.5
Sun's first and upper limb	R	51 04	232 38	36	37.0	16 16	17	16.5
	....	52 05	52	50	51.0	11	13	12.0
	....	53 21	233 12	09	10.5	03	07	05.0
Means	....	7 49 51.3	52	..	38.2	16	..	07.4
Azimuth mark	R	.....	233 56	55	55.5	....	..	...
	D	.....	53 58	58	58.0	....	..	...
Means	....	.....	53	..	56.8	....	..	...

Computation of Azimuth of Mark.

Formula, $\tan^2 \frac{1}{2} A = \frac{\sin(s-\phi)\sin(s-h)}{\cos s \cos(s-p)}$

where A = azimuth from north.
ϕ = latitude.
h = corrected altitude.
p = polar distance.
$s = \frac{1}{2}(\phi + h + p)$.

Computation of Chronometer Correction.

Formula, $\tan \frac{1}{2} t = \cot \frac{1}{2} A \frac{\sin(s-h)}{\cos(s-p)}$

where t = hour angle of sun.

Date, 1896.	Sept. 18. P. M.	Sept. 18. P. M.
	h. m. s.	h. m. s.
Chronometer time	7 42 21.5	7 49 51.3
Correction to 1842 on G. M. T.	+2 09.8	+2 09.8
Greenwich mean time	7 44 31.3	7 52 01.1
Sun's apparent declination	1° 26′.9	1° 26′.8
Sun's north polar dist. $= p$	88° 33′.1	88° 33′.2
h observed	16° 46′.4	16° 07′.4
Correction for parallax	+0′.1	+0′.1
Correction for refraction	−3.1	−3.3
h corrected	16 43.4	16 04.2
p	88 33.1	88 33.2
ϕ	64 53.5	64 53.5
$\frac{1}{2}(h+p+\phi) = s$	85 05.0	84 45.4
$s - \phi$	20 11.5	19 51.9
$s - h$	68 21.6	68 41.2
$s - p$	−3 28.1	−3 47.8
Log sin $(s-\phi)$	9.53802	9.53124
Log sin $(s-h)$	9.96826	9.96923
Log numerator	9.50628	9.50047
Log cos s	8.93301	8.96090
Log cos $(s-p)$	9.99920	9.99904
Log denominator	8.93221	8.95994
Log $\tan^2 \frac{1}{2} A$	0.57407	0.54053
Log $\tan \frac{1}{2} A$	0.28704	0.27026
$\frac{1}{2} A$	62° 41.4′	61° 46.6′
A	125 22.8	123 33.2
Horiontal circle reads	50 48.4	52 38.2
True meridian reads	176 11.2	176 11.4
Azimuth mark reads	53 56.8	53 56.8
Mark west of north	122 14.4	122 14.6

Date, 1896.	Sept. 18. P. M.	Sept. 18. P. M.
Log cot $\frac{1}{2} A$	9.71296	9.72974
Log sin $(s-h)$	9.96826	9.96923
Log numerator	9.68122	9.69897
Log cos $(s-p)$	9.99920	9.99904
Log tan $\frac{1}{2} t$	9.68202	9.69993
$\frac{1}{2} t$	25° 40′.9	26° 37′.0
t	51° 21′.8	53° 14′.0
	h. m. s.	h. m. s.
t in time	3 25 27.2	3 32 56.0
Equation of time	−6 14.7	−6 14.8
Local mean time	3 19 12.5	3 26 41.2
1842 reads	7 42 21.5	7 49 51.3
Correction on local *m. t.*	−4 23 09.0	−4 23 10.1

SECTION 20. *Example of Observations of Magnetic Declination.* Station, Sydney, Nova Scotia. Date, July 11, 1896. Instrument, Magnetometer 19. Magnet 19L suspended, scale erect. Line of detorsion, 330°.

Local time. A. M.	Scale Readings. Left.	Right.	Mean.	
h. m.	d.	d.	d.	Azimuth circle, A. 11° 04′. B. 191° 04′.5.
7 10	38.8	49.1	43.95	
15	42.2	45.9	44.05	
40	42.3	46.9	44.60	East elongation.
57	39.0	47.5	43.25	
8 17	39.0	46.3	42.65	
56	35.2	48.4	41.80	
P. M.	Line of detorsion, 280°.			Azimuth circle, A. 10° 58′. B. 190° 59′.
12 35	32.4	41.0	36.70	
12 45	30.6	40.1	35.35	
1 25	24.8	44.1	34.45	West elongation.
35	28.3	41.7	35.00	
48	28.1	43.8	35.95	

READINGS OF AZIMUTH MARK.

At beginning of A. M. observations	262°	47′
At end of A.M. observations	262	47.5
At beginning of P.M. observations	262	41
At end of P.M. observations	262	41.2
Mean	262°	44′.2

DETERMINATION OF AXIS OF MAGNET. (Magnet observed alternately erect and inverted.)

Scale.	Scale Readings.		Mean.	Alternate Mean.	Axis.
	d.	d.	d.	d.	d.
E	40.3	45.1	42.70	....	....
I	35.2	23.0	29.10	42.70	35.90
E	33.5	51.9	42.70	29.00	35.85
I	38.8	19.0	28.90	42.52	35.71
E	34.7	50.0	42.35	28.72	35.54
I	29.8	27.3	28.55	42.12	35.34
E	35.8	48.0	41.90	....	....
				Mean	35.67

Mean scale reading of east and west magnetic elongation			39.52
Reduction to axis	°	+07′.7 = difference =	3.85
Azimuth circle reads	11	01.4	
Magnetic south meridian reads	11	09.1	
Magnetic north meridian reads	191	09.1	
Mean reading of mark	262	44.2	
Azimuth of mark E. of N.	46	43.7	
True meridian reads	216	00.5	
Magnetic declination	24	51.4 W. of N.	

SECTION 21. *Example of Observations of Magnetic Dip.* Station, Sydney, Nova Scotia. Date, July 11, 1896. Dip Circle, No. 4,655. Needle No. 2.

POLARITY OF MARKED END B NORTH.

Circle East.				Circle West.			
Face East.		Face West.		Face East.		Face West.	
S.	N.	S.	N.	S.	N.	S.	N.
° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
73 59	73 61	74 02	74 04	75 35	75 29	75 31	75 28
61	60	01	04	31	24	29	26
73 60.0	73 60.5	74 01.5	74 04.0	75 33.0	75 26.5	75 30.0	75 27.0
73 60.2		74 02.8		75 29.8		75 28.5	
	74 01.5				75 29.2		

Mean, 74° 45′.4.

POLARITY OF MARKED END B SOUTH.

Circle West.				Circle East.			
Face West.		Face East.		Face West.		Face East.	
S.	N.	S.	N.	S.	N.	S.	N.
° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
74 57	74 52	75 34	75 31	73 41	73 38	74 10	74 09
58	50	33	31	40	39	18	15
74 57.5	74 51.0	75 33.5	75 31.0	73 40.5	73 38.5	74 14.0	74 12.0
74 54.2		75 32.2		73 39.5		74 13.0	
	75 13.2				73 56.2		

Mean, 74° 34′.7.

Resulting Dip, 74° 40′.0.

	h.	m.
Local time of beginning	11	28 A.M.
Local time of ending	11	55 A.M.
Magnetic meridian reads	61°	16′

DETERMINATION OF MAGNETIC MERIDIAN.
Circle in magnetic prime vertical.

	° ′
Circle N, Needle N.	57 43
Circle N, Needle S.	58 12
Circle S, Needle N.	64 47
Circle S, Needle S.	64 23
Mean	61 16

The above scheme of observation comprises a complete system of reversals of the position of the needle, the position of the circle, and the polarity of the ends of the needle, with the idea of eliminating all sources of error due to the form and magnetism of the needle, etc.

SECTION 22. *Example of Observations and Computation of Horizontal Intensity of Earth's Magnetism.* — The method used depends on the determination of two relations between the horizontal intensity (H) and the magnetic moment (m) of the principal magnet used. By using this magnet to deflect another magnet suspended in the earth's field, the relation $\frac{m}{H}$ is obtained, and by oscillating the principal magnet the product $m\,H$ is determined, and by combining these two results m and H are found. The observations and reductions required are shown in the following forms, together with the formulas used.

DEFLECTIONS WITH THEODOLITE MAGNETOMETER.

Date, July 11, 1896. Station, Sydney, Nova Scotia. Instrument, Magnetometer 19. Magnet 19L, deflecting at right angles to Magnet 19*s* suspended. Deflecting distance $r = 49$ cm.

Magnet.	North end.	Circle Readings. No.	A	B	Mean.	Circle Readings. No.	A	B	Mean.
			° ′	′	′		° ′	′	′
East.	E.	1	193 35.5	34	34.75	....	.....	....	....
	W.	.....	.....	....	....	2	188 17	16	16.50
	E.	3	37	35	36.00	....	.....	....	....
	Mean.		193		35.38		188		16.50
West.	W.	...	.....	..	....	6	188 23.5	22	22.75
	E.	7	193 30	28	29.00	..	.....	..	....
	W.	...	.....	..	....	8	23.5	21	22.25
	Mean.		193		29.00		188		22.50

Computation: $\frac{m}{H} = \frac{1}{2} r^3 \sin u \left(1 - \frac{P}{r^2} \ldots .\right)$

	°	′		Logarithms.
Magnet East, $2u =$	5	18.88		
Magnet West, $2u =$	5	06.50	$\frac{1}{2}$	9.69897
Mean	5	12.69	r^3	5.07112
$u =$	2	36.34	Sin u	8.65763
			$1 - \frac{P}{r^2}$	0.00076
	h.	m. A.M.	°C.	
Time of beginning . .	10	30	Temperature . . . 17.2	$1 + \frac{2hm}{r^3}$ 0.00004
Time of ending . . .	10	43	Temperature . . . 23.5	
Mean	10	36	$t =$ 20.4	$\frac{m}{H}$ 3.42852

P is the so-called distribution coefficient.

$1 + \frac{2hm}{r^3}$ is the induction correction.

OBSERVATIONS OF OSCILLATIONS.

Date, July 11, 1896. Station, Sydney, Nova Scotia. Instrument, Magnometer 19. Magnet, 19L. Chronometer, 1823 (sidereal) daily rate 235.0 gaining on mean time.

Number of oscillations.		Chronometer time.	Temperature t'.	Extreme scale readings.		Time of 100 oscillations.
		h. m. s.	°C.			m. s.
Right	0	9 28 52.3	23.7	22.9	37.2	.....
	10	29 44.6	....	....	....	.....
	20	30 37.2	....	....	....	.....
Left	31	31 34.7	....	....	....	.....
	41	32 27.0	....	....	....	.....
	51	33 19.4	....	....	....	.....
Right	100	9 37 36.6	....	....	....	8 44.3
	110	38 29.0	....	....	....	44.4
	120	39 21.1	....	....	....	43.9
Left	131	40 19.0	....	....	....	44.3
	141	41 11.5	....	....	....	44.5
	151	42 03.7	18.2	24.9	34.1	44.3
(10 h. 14 m. A.M.) Means.			21.0	24.	36.	8 44.28

Determination of coefficient of torsion. Value of one scale div'n = 2'.0.

Torsion circle.	Scale.		Mean.	Differences.		Logarithms.
330	24.9	34.1	29.50		$v = 3.4$	
				1.50	$5400' + v'$	3.73267
60	24.0	38.0	31.00			
				3.50	5400 (ar. co.)	6.26761
240	23.0	32.0	27.50			
				1.75	$1 + \frac{h'}{f}$	0.00028
330	22.5	36.0	29.25			
			Mean v =	1.69		

COMPUTATION.

$$T^2 = T'^2 \left(1 + \frac{k'}{f}\right) \left(1 - (t' - t)\, q\right) (1 + h\, H)$$

where the quantities in the parentheses are respectively the torsion, temperature, and induction corrections, and T is the corrected time of oscillation.

		s.
Observed time of 100 oscillations	=	524.28
Time of one oscillation	=	5.2428
Correction for rate	= −	.0143
Correction for arc	=	.0000
	T' =	5.2285

			Logarithms.
q	.00049		
$t' - t$	21.0 − 20.4 = + 0.6	T'	0.71838
$(t' - t)\, q$	+ .00029	T'^2	1.43676
		$1 + \frac{k'}{f}$	0.00028
$1 - (t' - t)\, q$	0.99971	$1 - (t' - t)\, q$	9.99987
		$1 + h\, H$	0.00084
$m\, H = \frac{\pi^2 M}{T^2}$		T^2	1.43775
where m = magnetic moment of magnet		(ar. co.) T^2	8.56225
H = horizontal force of earth's magnetism		π^2	0.99430
M = moment of inertia of magnet		M	2.25145
T = time of oscillation.		$m\, H$	1.80800
m = 415.2 (at 22.2 °C.)		m	2.61826
H = 0.1548		H	9.18974

Observations of deflections, { Date, July 11. Hour, 10 h. 36 m. A.M.
Temperature t = 22°.2C.

	$\frac{m}{H}$	3.42852
	$m\, H$	1.80800
	m^2	5.23652
	m	2.61826

SECTION 23. *Example of Time Observations in Connection with Pendulum Work.* — In Table P is given an example of one night's time observations at Umanak, using the star list given in Table O. The transits of eight stars (four in each position of the telescope) across the meridian were observed by the eye and ear method, noting the time of passage across each of five lines. The value of one division of the striding level of meridian telescope No. 13 (used in these observations) was $1''.68 = 0^s.112$. To obtain the level error (b) of the instrument, one-fourth this amount (or $0^s.028$) is to be multiplied into the sum of the readings west end of level minus sum of readings of east end. In this form the means of the times are taken for each star, and the diurnal aberration (K) and level (Bb) corrections are applied, and compared with the apparent right ascensions of the stars as taken from the Berliner Jahrbuch or the American Ephemeris. The resulting values, $a - t$, are the chronometer corrections not yet free from the collimation (c) and azimuth (a) errors of the instrument. In Table Q is shown the computation of these errors and the derivation of the final chronometer correction by the field method of time computation.[1] The three stars of small declination (time stars) of each group are combined and treated as one star by taking the means of their $a - t$, C and A respectively. A first approximation to c is found by dividing the difference between the $a - t$ for the two groups of time stars (positions E and W) by the difference of the mean C. Applying then the collimation correction ($- Cc$), the quantities $a - t - Cc$ result. The azimuth errors (a_e and a_w) are next derived by dividing the difference between $a - t - Cc$ for time stars, and azimuth stars by the difference in A, treating each position of the instrument separately. The azimuth corrections (Aa) are next applied, and if the resulting values $a - t - Cc - Aa$ differ for the two positions it indicates that the first value of c may be improved. The difference may be regarded as the effect of collimation error, and treated as before to obtain a correction to c. With improved values of c, a_e and a_w this method may be continued until the chronometer corrections in the two positions of the instrument agree. In general where the stars for observation are conveniently chosen, the first approximation will be sufficient, as it would be in this example. When satisfactory val-

[1] This field method of reducing time observations is more fully explained in App. No. 9, Report C. and G. Survey for 1896 (not yet published).

ues of c, a_e and a_w are obtained, the corrections Cc and Aa are applied to each star separately, and the chronometer corrections ($\triangle T$) and residuals (v) derived. The mean of the former is taken as the final chronometer correction at the epoch of the mean of the right ascensions.

TABLE O. — STAR LIST FOR OBSERVING, AND STAR FACTORS FOR COMPUTATION, FOR UMANAK, GREENLAND. Latitude, $(\phi) = 70° 40'$ N.

Star.	Magnitude.	Right ascension α.	Declination δ.	Zenith distance $\zeta = \phi - \delta$.	Star Factors.			Correction for diurnal aberration $.0206 \cos \phi \sec \delta = K$.
					Azimuth $\sin(\phi - \delta) \sec \delta = A$.	Collimation $\sec \delta = C$.	Level $\cos(\phi - \delta) \sec \delta = B$.	
		h. m. s.	° ′	° ′				s.
ε Cygni	2.6	20 42 04	33 35	+37 05	+ .72	1.20	.95	—.01
76 Draco.	6.0	50 11	82 09	—11 29	—1.46	7.32	7.17	—.05
υ Cygni	4.0	53 21	40 46	+29 54	+ .66	1.32	1.15	—.01
61 Cygni pr.	5.7	21 02 17	38 14	+32 26	+ .68	1.28	1.07	—.01
ζ Cygni	3.0	08 34	29 48	+40 52	+ .76	1.15	.87	—.01
τ Cygni	4.0	10 42	37 36	+33 04	+ .69	1.27	1.06	—.01
α Cephei	2.6	16 09	62 09	+ 8 31	+ .32	2.14	2.12	—.01
1 H. Draco. . . . . (Sub-polar).	4.5	22 16	98 13	—27 33	+3.24	—7.00	—6.20	+.05

TABLE P. — STAR OBSERVATIONS FOR TIME AT UMANAK, August 8, 1896.

Star.	ε Cygni.	76 Draco.	ν Cygni.	61 Cygni pr.	ζ Cygni.	τ Cygni.	α Cephei.	1 H. Draco.
Position of instrument.	E.	E.	E.	E.	W.	W.	W.	W.
Level readings. Direction of objective.	N. W. end. E. end.	S. W. end. E. end.	N. W. end. E. end.	Mean N. +1.25	S. W. end. E. end.	S. W. end. E. end.	N. W. end. E. end.	Mean N. +0.30
Level readings. Level in first position.	Div. 8.3 16.0	Div. 16.9 7.7	Div. 8.1 16.1	Mean S. +0.90	Div. 7.8 16.9	Div. 8.3 16.0	Div. 16.4 7.9	Mean S. +0.35
Level readings. Level reversed . . .	16.9 7.9	8.0 16.3	16.9 7.7	Mean +1.08	16.5 8.0	16.8 7.8	8.0 16.2	Mean +0.32
Level readings. Sums	25.2 23.9	24.9 24.0	25.0 23.8	s. +1.08 × 0.28	24.3 24.9	25.1 23.8	24.4 24.1	s. +0.32 × 0.28
Level readings. Σ W − Σ E . . .	+1.3	+0.9	+1.2	s. = +.030 = $\delta\varepsilon$	−0.6	+1.3	+0.3	= +.009 δ_w
Transit observations . .	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.
Line 5	0 09 01.6	0 16 51.0	0 20 15.7	0 29 13.6	0 35 33.2	0 37 37.8	0 42 41.5	0 48 57.0
Line 4	18.0	17 17.5	33.7	31.0	49.3	55.6	43 11.0	49 21.5
Line 3	34.5	42.0	52.1	48.6	36 05.0	38 13.0	40.8	44.5
Line 2	51.4	18 07.0	21 10.5	30 06.5	21.2	30.5	44 10.5	50 09.5
Line 1	10 07.9	33.0	28.6	24.3	37.1	48.0	40.4	34.0
Means	0 09 34.68	0 17 42.10	2 20 52.12	0 29 48.80	0 36 05.16	0 38 12.98	0 43 40.84	0 49 45.30
Diur. aber. corr. = K . .	−.01	−.05	−.01	−.01	−.01	−.01	−.01	+.05
Level correction = Bb . .	+.03	+.22	+.03	+.03	+.01	+.01	+.02	−.06
Time partly corrected = t	0 09 34.70	0 17 42.27	0 20 52.14	0 29 48.82	0 36 05.16	0 38 12.98	0 43 40.85	0 49 45.29
Right ascension = α	20 42 03.53	20 50 10.54	20 53 21.01	21 02 17.45	21 08 33.95	21 10 41.71	21 16 09.10	21 22 16.12
$\alpha - t$	− 3 27 31.17	− 3 27 31.73	− 3 27 31.13	− 3 27 31.37	− 3 27 31.21	− 3 27 31.27	− 3 27 31.75	− 3 27 29.17

TABLE Q. — COMPUTATION OF CHRONOMETER CORRECTION FROM STAR OBSERVATIONS AT UMANAK, August 8, 1896.

Star.	Position.	$a-t$	C	A	Cc	Aa	ΔT	v	
		h. m. s.			s.	s.	s.	s.	
ε Cygni	E.	−3 27 31.17	−1.20	+ .72	+.09	+ .33	−31.59	− .05	Final chronometer correction at 21 h. 03 m. (local sidereal time).
76 Draco	E.	31.73	−7.32	−1.46	+.58	− .67	−31.64	.00	
ν Cygni	E.	31.13	−1.32	+ .66	+.10	+ .30	−31.53	− .11	h. m. s.
61 Cygni pr.	E.	31.37	−1.28	+ .68	+.10	+ .31	−31.78	+ .14	$\Delta T = -3\ 27\ 31.64$
ζ Cygni	W.	31.21	+1.15	+ .76	−.09	+ .45	−31.57	− .07	
τ Cygni	W.	31.27	+1.27	+ .69	−.10	+ .41	−31.58	− .06	
α Cephei	W.	31.75	+2.14	+ .32	−.17	+ .19	−31.77	+ .13	
1 H. Draco	W.	29.17	−7.00	+3.24	+.55	+ 1.92	−31.64	.00	
First approximation		$a-t$	C	A	Cc	$a-t-Cc$	Aa'	$a-t-Cc-Aa$	
Mean of time stars	E.	− 31.22	−1.27	+ .69	+.09	−31.31	+ .30	−31.61	$c = -.068$ s.
Azimuth star	E.	− 31.73	−7.32	−1.46	+.50	−32.23	− .62	−31.61	$a_E = +.428$
									$a_W = +.627$
Mean of time stars	W.	− 31.41	+1.52	+ .59	−.10	−31.31	+ .37	−31.68	
Azimuth star	W.	− 29.17	−7.00	+3.24	+.48	−29.65	+ 2.03	−31.68	
Final approximation									
Mean of time stars	E.	− 31.22	−1.27	+ .69	+.10	−31.32	+ .32	−31.64	$c = -.079$. s.
Azimuth star	E.	− 31.73	−7.32	−1.46	+.58	−32.31	− .67	−31.64	$a_E = +.460$
									$a_W = +.593$
Mean of time stars	W.	− 31.41	+1.52	+ .59	−.12	−31.29	+ .35	−31.64	
Azimuth star	W.	− 29.17	−7.00	+3.24	+.55	−29.72	+ 1.92	−31.64	

SECTION 24. *Example of Pendulum Observations.* — Umanak, Greenland, August 10, 1896. Swing No. 5. Pendulum *A* 6, reversed on knife-edge I.

	Coincidences Observed.		Arc.	Pressure.	Dummy thermometer.	Air thermometer.
	Chronometer 1,842.	Chronometer 177.				
	h. m. s.	h. m. s.		mm.	°C.	°C.
	Up 1 01 17	Down 12 59 35	4.5 mm. = 52′	67.3	11.05	10.55
	Down 1 04 18	Up 1 02 33				
	Up 1 07 17	Down 1 05 31				
	Down 1 10 16	Up 1 08 28				
	Down 8 30 41	Up 8 28 50				
	Up 8 33 39	Down 8 31 44				
	Down 8 36 37	Up 8 34 42				
	Up 8 39 35	Down 8 37 38	1.6 mm. = 19′	68.7	10.6	10.6
Interval from down coincidences	7 32 19	7 32 07	Means	68.0	10.82	
Interval from up coincidences	7 32 18	7 32 09	Reduction to 0°C.	−2.5	−0.12	Thermo correction.
Mean interval	7 32 18	7 32 08		65.5	10.70	
	= 27138 s.	= 27128 s.				
Approximate time of two coincidence intervals	s. 357.5	s. 354.2				
Number of coincidence intervals	152	154				
Time in one coincidence interval	s. 178.54	s. 176.16				

The balance of the computation is summarized in the tables of results (H).

AN ANALYTICAL INVESTIGATION OF THE HYDROLYSIS OF STARCH BY ACIDS.[1]

By GEORGE W. ROLFE, A.M., and GEORGE DEFREN, M.S.

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Few problems of commercial analysis have been so complicated and so discouraging as that of the determination of the components of starch conversion products. The well-known schemes of commercial analysis of worts and similar products of the action of diastase are based on the assumption that but two simple compounds are formed from the starch — maltose and dextrin. In the case of glucose syrups and starch sugars, which are the results of acid hydrolysis, it is known that the reaction proceeds farther, as dextrose is formed from the maltose and dextrin.

Musculus and Gruber[2] decided that these reactions went on together, so that, except at the very beginning or final stage of hydrolysis, all of these compounds must be present in solution.

The analysis of acid-converted starch products must, therefore, take into consideration the presence of the third compound, dextrose.

Much doubt, however, has been thrown on the accuracy of such analyses, as during the past twenty years the researches of O'Sullivan,

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Note. — Among the numerous errors incident to compilation, the authors have had their attention drawn to an important clerical error which had been carried through the calculation of Tables C and E. These tables have therefore been recalculated in this reprint. While these corrections have changed the carbohydrate values of Table C somewhat and the constants of Table E, the values of K remain unchanged, and the tabulated results in Tables I, II, and III are not materially affected. Of the plate, Figure 3 is the only one affected by these corrections, and as the character of the curves remains unchanged it was not thought worth the trouble to prepare a new plate drawn exactly to scale, especially as the correction on a plot of this size is hardly noticeable. In short, the main results of the investigation remain as originally set forth.

[1] Reprinted from the Journal of the American Chemical Society, **18**, No. 10, October, 1896. (Received July 3, 1896.)

[2] Bull. Soc. Chim., **2**, 30.

Brown, Heron, Morris, Bondonneau, Herzfeld, Musculus, Bruckner, Fischer, and other distinguished investigators, have shown that not only the simple compounds referred to can be isolated from starch products, but also many others of quite distinct optical and chemical properties. Space will not permit a review of this work, which is in many points conflicting. The recent conclusion of Lintner and Düll is that the following compounds result from hydrolysis:[1]

Hydrolysis with oxalic acid.	With diastase.
Amylodextrin.	Amylodextrin.
Erythrodextrin I.	Erythrodextrin I.
Erythrodextrin IIα.	.....
Erythrodextrin IIβ,	.....
Achroodextrin I.	Achroodextrin I.
Achroodextrin II.	Achroodextrin II.
Isomaltose.	Isomaltose.
Dextrose.	Maltose.

Others, as Brown and Morris,[2] deny the existence of the isomaltose of Fischer, Lintner, and Düll, and mention another compound, maltodextrin, as intermediate between dextrin and maltose.[3]

In 1885, Brown and Morris[4] discovered the remarkable law that at any stage of the conversion of starch by diastase, the total product, in its optical properties and relation to Fehling solution, behaved exactly as if made up of two components only, maltose and dextrin, so that it was possible by taking the rotatory power to calculate at once the cupric reducing power if the total carbohydrates were known. This law indicated that, however complicated the bodies isolated, they could be considered as existing in solution as two simple compounds, and did much to establish the validity of the principles of the usual commercial analyses of beer worts and similar products.

The method of analysis of glucose syrups and starch sugars implies the assumption of a similar law, but the proof that this law actually exists under varying conditions of hydrolysis apparently has not been worked out.

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[1] Ber. d. chem. Ges., **28**, 1522–1531.

[2] J. Chem. Soc., No. 393 (August, 1895).

[3] A very complete bibliography of the original publications on the carbohydrates is in Tollen's Handbuch der Kohlenhydrate, **1**, 331–360 (1888); **2**, 368–398 (1895).

[4] Ann. Chem. (Liebig), **231**, 131.

Our investigations have been made, first, to determine whether there was any simple constant relation between the optical rotation and the cupric reducing powers of starch products hydrolyzed under different conditions; and, secondly, whether any laws could be found affecting the three simple bodies assumed to be formed and determined by the usual methods of analysis.

Incidentally we have collected some data as to the speed of hydrolysis, influence of carbohydrates on specific gravity of solutions, and some looking to the adoption of a more rapid and accurate method of determining cupric reducing power by Fehling solution. The latter data are included in a separate paper. The work on specific gravities is not yet sufficiently complete for publication.

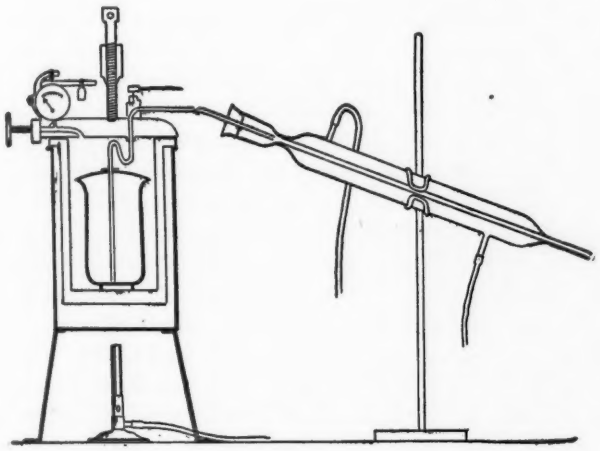

FIG. 1.

An autoclave of the usual construction was modified in the following manner: The thermometer tube was taken out and in its place was attached a specially constructed valve, by means of which liquor cooking in a beaker in the interior could be removed at any time during the progress of the experiment. This superheated liquor was prevented from vaporizing by passing through a condenser. Excessive condensation into the beaker was prevented in large part by a well-fitting lead cap. The illustration sufficiently explains the apparatus.

In most of the work, about 100 grams of a good quality of commercial corn starch[1] was mixed with a liter of water containing the hydrolyzing acid. Samples of from 50 cc. to 75 cc. of the liquor were removed at different stages of the conversion, and immediately shaken up with a few grams of marble dust. Two drops of tenth normal sodium hydroxide solution were then added to the sample, which was cooled and filtered. This method of neutralization, except in cases of very low converted samples, gave an absolutely clear filtrate, the filtration being exceedingly rapid, and the removal of the albuminoids being practically complete. Low converted products often required to be heated with aluminum hydroxide before filtering.

The samples were tested as follows:

(1) For specific gravity by Westphal balance, corrected to a temperature of 15.5° C.

(2) Specific rotatory power ($[a]_D$) by a Schmidt and Haensch half-shade saccharimeter.

(3) Cupric reducing power by means of Fehling solution.

Total Solids. — Total solids were calculated from the specific gravity of the solution by the factor 0.00386, which was taken to represent the influence of 1 gram of the mixed carbohydrates in 100 cc. of solution. Corrections were made when necessary for the influence of other substances in solution, not carbohydrates. This factor 386 is practically that of Balling and Brix, and has been found exact for approximately 10 per cent. solutions of cane sugar, and the balance of evidence seems to be that it is correct for starch products.[2]

We have made several determinations of this factor by drying 10 cc. of solution on rolls of dried paper at a temperature of 100–105° C. Our results point to the constancy of this factor 386, even in solutions of low rotatory power, but are not yet complete enough to establish the value for all rotations.

Therefore, in this work we have adopted the expedient used by Brown and Morris, and others, and calculated all optical and copper

[1] An analysis of this starch by the usual commercial methods gave:

	Per cent.
Starch	89.15
Oil	0.14
Ash	0.12
Albuminoids	0.42
Water	10.21
	100.04

[2] Recent results have modified our views on this point, but as used in our *calculations* the factor 386 is correct.

reduction constants on the assumption that all three carbohydrates in solution affect the specific gravity like cane sugar when the concentration is approximately 10 per cent. Even if subsequent investigations show that this view is not exactly correct, the relative values of the constants will not be appreciably affected nor the truth of the laws as set forth.

To illustrate this method of calculation of constants we give the following from our own determinations :

10 grams of dextrose dissolved in 100 cc. of water gave a rotation of 30.70° on the Schmidt and Haensch saccharimeter. This gives $[a]_D$ as 52.8.[1] As the increase in specific gravity per gram of crystallized dextrose in 100 cc. is 0.00381, $[a]_{D386}$ is 53.5.

9.751 grams of crystallized maltose anhydride in 100 cc. of water gave a rotation of 77.40. This gives an absolute specific rotatory power of 136.6. The specific gravity factor of maltose being 0.00390, $[a]_{D386}$ is 135.2°. No exact figure is known for the influence of crystallized dextrin on the specific gravity of its solution. O'Sullivan gives 0.00385, and the balance of evidence seems to favor this. Hence 195 is probably correct for $[a]_{D386}$.[2]

In like manner the values for K have been reduced to a dextrose with the factor 386.

Specific Rotatory Power. — All readings were made as nearly as possible at a temperature of 20° C. in 200 mm. tubes, the mean of several readings being taken. Corrections for zero error were made frequently, and the instrument was carefully screened by glass plates from the heat of the lamps. Comparisons were made with a Laurent polariscope to determine the value of the division in terms of angular degrees for sodium light, the accuracy of the quartz wedges having been verified previously. With standard quartz plates the usual factor 0.346 was obtained, but solutions of commercial glucose of approximately 10 per cent. gave the figure 0.344, which agrees with the recent work of Rimbach[3] and other investigators. We have taken, therefore, the latter factor in our calculation.

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[1] Precautions against bi-rotation were taken in both examples cited.

[2] Brown and Heron. Ann. Chem. (Liebig), **199**, 190–243.

[3] Ber. d. Chem. Ges., **27**, 2282.

TABLE A.

COMPARISON OF SCHMIDT AND HAENSCH HALF-SHADE SACCHARIMETER WITH THAT OF LAURENT POLARISCOPE READING IN ANGULAR DEGREES.

	S. AND H. SACCHARIMETER. (Using bat-wing burner and lens.)			LAURENT POLARISCOPE. (Sodium flame.)			
Test.	Reading.	Zero error.	Corrected reading.	Reading.	Zero error.	Corrected reading.	Factor.
$t = 20-22$)							
Quartz A . . .	62.965	0.300	62.665	21° 40′	0	21.666°	0.3457
Quartz A . . .	62.800	0.150	62.650	21° 40′	0	21.666°	0.3458
Quartz A . . .	62.970	0.290	62.680	21° 40.2′	0.6′	21.660°	0.3458
Quartz A . . .	62.836	0.130	62.706	21° 40.7′	0.6′	21.666°	0.3455
Glucose A . . .	77.510	0.277	77.233	26° 35′	0	26.582°	0.3442
Glucose B . . .	76.355	0.150	76.205	26° 15.3′	0	26.254°	0.3445
Glucose B . . .	76.355	0.150	76.205	26° 14′	0	26.233°	0.3442
Glucose C . . .	76.535	0.150	76.385	26° 18′	0	26.300°	0.3443
Glucose D . . .	76.110	0.130	75.980	26° 10.3′	0.6′	26.162°	0.3443
($t = 25$)							
Hydrolyzed starch products . . .	E. 92.73[1]	00	92.73	31° 56′	—1′	31.95°	0.3445
	F. 24.84	00	24.84	8° 32′	—1′	8.55°	0.3442

Cupric Reducing Power. — Our method is practically that of O'Sullivan, first published in 1876. The copper is weighed as the oxide. We have found this method exact and rapid. An analytical investigation of this process has been made by one of us, and given in detail in a separate paper.

Plotted Results. — To show the relationship of the copper-reducing power, and the specific rotatory power of the products formed during the progress of the hydrolysis of the starch, we have plotted our results, taking as abscissæ the decreasing values of the rotatory power, from the amylodextrin stage (195°) to that of dextrose ($[a]_{D386} = 53.5°$), and as ordinates the cupric reducing power (K_{386}) taking that of an equivalent weight of dextrose as 100.[2] (See Figure 2.)

[1] Using Welsbach burner.

[2] Data given in Table B.

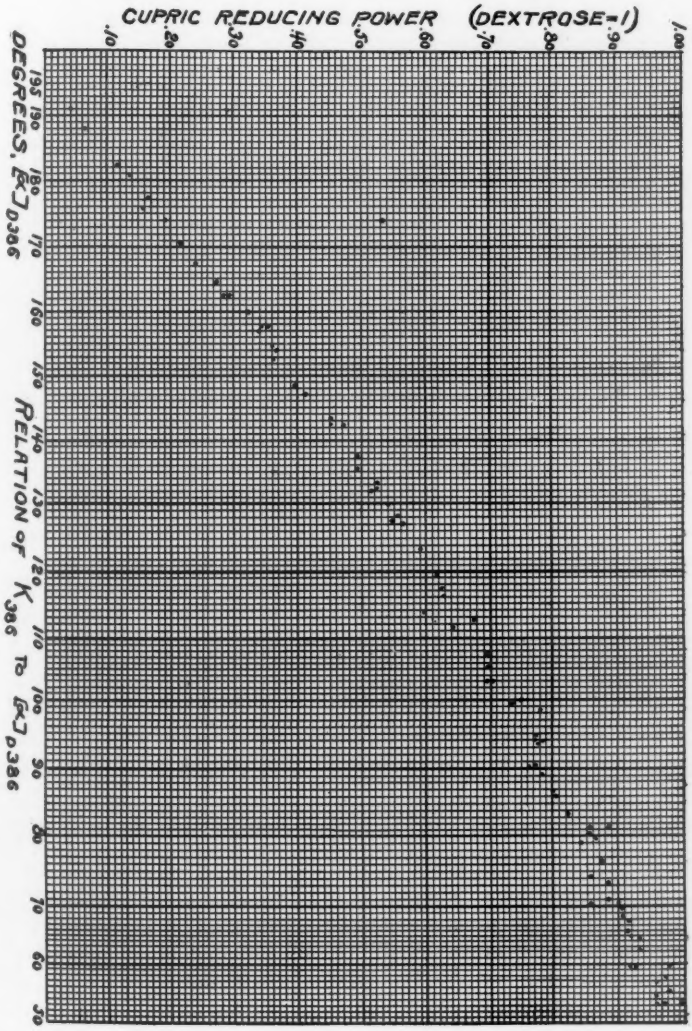
CUPRIC REDUCING POWER (DEXTROSE=1)
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.00
DEGREES, $[\alpha]_{D}^{386}$
195
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
RELATION OF K_{386} TO $[\alpha]_{D}^{386}$

FIG. 2.

TABLE B.[1]

HYDROLYSIS OF STARCH. EXPERIMENTAL DATA.

Run.	Number of sample.	Minutes cooking.	Grams starch.	Atmospheres pressure.	Acid. Kind.	Acid. Concent.	Amount cc.	Water cc.	Specific gravity 15.5.	Saccharimeter reading.	Copper oxide.	$[\alpha]_D$ 386.	K 386.
8a	2	30	110	2	HCl	$\frac{n}{10}$	10	990	1.0456	98.0	0.1552[2]	142.7	0.4747
	3	45	...	..	....	..	...	...	1.0394	59.3	0.2103	99.95	0.7480
	4	75	...	..	....	..	...	...	1.0374	41.5	0.2275	73.67	0.8537
	5	135	...	..	....	..	...	...	1.0367	32.9	0.2480	59.53	0.9283
10	1	15	110	2	HCl	$\frac{n}{10}$	10	990	1.0199	57.3	0.0060	191.30	0.0412
	2	45	...	..	....	..	...	...	1.0320	84.8	0.0366	176.0	0.1567
	3	75	...	..	....	..	...	...	1.0348	80.7	0 0923	154.0	0.3652
	4	100	...	..	....	..	...	...	1.0315	67.6	0.1026	142.5	0.4523
	5	130	...	..	....	..	...	...	1.0315	60.8	0.1258	128.1	0.5584
	6	160	...	..	....	..	...	...	1.0318	54 6	0.1368	114.0	0.5993
	7	190	...	..	....	..	...	...	1.0318	49.4	0.1594	103.1	0 6995
	8	220	...	..	....	..	...	...	1.0318	44.7	0.1781	93.95	0.7827
	9	250	...	..	....	..	...	...	1.0323	42.2	0.1848	86.66	0.8000
	10	280	...	..	....	..	...	...	1.0323	38.4	0.1940	78.94	0.8407
11	1	15	110	2	HCl	$\frac{n}{10}$	100	900	1.0414	89.55	0 1290	143.6	0.4434
	2	30	...	..	....	..	...	...	1.0417	55.95	0 2320	89.10	0.7825
	3	45	...	..	....	..	...	...	1.0419	41.0	0.2747	64.98	0.9230
	4	60	...	..	....	..	...	...	1.0414	36.0	0.2837	57.75	0.9663
	5	75	...	..	....	..	...	...	1.0412	33.0	0.2830	53.19	0.9685
	6	90	...	..	....	..	...	...	1.0406	32.5	0.2763	53.16	0.9590
13	1	15	110	2	HCl	$\frac{n}{10}$	100	900	1.0394	103.2	0.0056	174.0	0.1958
	2	45	...	..	....	..	...	...	1.0384	75.7	0.1500	129.9	0.5405
	3	60	...	..	....	..	...	...	1.0380	61.1	0.1898	105.7	0.6988
	4	90	...	..	....	..	...	...	1.0380	45.5	0.2339	79.50	0.8646
	5	120	...	..	....	..	...	...	1.0375	38.25	0.2448	67.75	0.9175
14	2	22½	110	2	HCl	$\frac{n}{10}$	100	900	1.0379	97.8	0.0661	167.4	0.2415
	3	35	...	..	....	..	...	...	1.0384	85.9	0.1095	148.6	0.3964
	4	52½	...	..	....	..	...	...	1.0370	64.75	0.1664	116.2	0.6279
	5	75	...	..	....	..	...	...	1.0374	50.80	0.2040	90.20	0.7640

[1] This table does not include all the data of Table E. Samples on which were made determinations of optical constants only have been omitted for lack of space.
[2] Obtained from a solution $\frac{n}{10}$ of the original concentration.

TABLE B. — *Continued.*

HYDROLYSIS OF STARCH. EXPERIMENTAL DATA.

Run.	Number of sample.	Minutes cooking.	Grams starch.	Atmospheres pressure.	Acid. Kind.	Acid. Concent.	Amount cc.	Water cc.	Specific gravity 15.5.	Saccharimeter reading.	Copper oxide.	$[\alpha]_D^{386}$.	K^{386}.
	6	105	...	..	....	..	....	....	1.0374	39.60	0.2281	70.31	0.8561
	7	135	...	..	....	..	....	....	1.0374	34.95	0.2493	62 34	0.9367
15	2	30	110	2	HCl	$\frac{n}{10}$	1000	....	1.0371	88.1	0.0890	157.7	0.3329
	3	60	...	..	....	..	....	....	1.0337	67.05	0.1247	132 1	0.5146
	4	90	...	..	....	..	....	....	1.0337	56 50	0.1551	111 4	0.6421
	5	120	...	..	....	..	....	....	1.0337	46.00	0.1863	90.65	0.7727
16	1	25	110	2	HCl	$\frac{n}{10}$	1000	....	1.0327	79.90	0.0679	162 3	0.2877
	2	40	...	..	....	..	....	....	1.0393	81.40	0.1395	137.5	0.4946
	3	50	...	..	....	..	....	....	1.0380	70.60	0.1617	123.4	0.5936
	4	75	...	..	....	..	....	....	1.0380	57.00	0.1994	99.61	0.7348
17	1	15	55	2	HCl	$\frac{n}{10}$	25	475	1.0360	105.5	0.0173	188.5	0.0643
	2	23	...	..	....	..	....	....	1.0341	92.9	0.0344	180.9	0.1393
	3	33	...	..	....	..	....	....	1.0343	88.1	0.0539	170.6	0.2173
	4	42	...	..	....	..	....	....	1.0352	86.2	0 0751	162.7	0.2963
	5	50	...	..	....	..	....	....	1.0308	79.5	0.0828	157.0	0.3396
18	1	75	60	2	HCl	$\frac{n}{10}$	50	450	1.0422	74.7	0.1892	117.6	0.6273
	2	90	...	..	....	..	....	....	1.0423	68.0	0.2100	106.8	0.6958
	3	110	...	..	....	..	....	....	1.0428	60.3	0.2369	93 56	0.7796
	4	120	...	..	....	..	....	....	1.0428	52.6	0.2587	81.62	0.8507
	5	135	...	..	....	..	....	....	1.0429	49.2	0.2676	76.05	0.8720
19	1	15	60	2	HCl	$\frac{n}{10}$	50	450	1.0383	105.0	0.0329	182.1	0.1186
	2	30	...	..	....	..	....	....	1.0374	87.0	0.0975	154.5	0.3619
	3	40	...	..	....	..	....	....	1.0374	66.2	0.1337	117.6	0.6255
	4	130	...	..	....	..	....	....	1.0359	39.8	0.2272	73.62	0.8882
	5	150	...	..	....	..	....	....	1.0326	34.8	0.2093	70.89	0.8997
20	1	45	60	2	$H_2C_2O_4$	$\frac{n}{10}$	50	450	1.0327	87.2	0.0396	177.1	0.1673
	2	90	...	..	....	..	....	....	1.0301	71.2	0.0766	157.7	0.3526
	3	120	...	..	....	..	....	....	1.0318	65.8	0.1125	135.5	0.4917
21	2	60	60	2	$H_2C_2O_4$	$\frac{n}{10}$	100	400	1.0352	75.9	0.1145	143.2	0.4523

TABLE B. — *Concluded.*

HYDROLYSIS OF STARCH. EXPERIMENTAL DATA.

Run.	Number of sample.	Minutes cooking.	Grams starch.	Atmospheres pressure.	Acid. Kind.	Acid. Concent.	Amount cc.	Water cc.	Specific gravity 15.5°.	Saccharimeter reading.	Copper oxide.	$[\alpha]_{D\ 386}$.	K_{386}.
	3	75	..	..	....	..	...	...	1.0359	71.6	0.1350	132.4	0.5237
	4	105	..	..	....	..	...	...	1.0355	64.0	0.1577	119.8	0.6200
24	1	30	65	2	HCl	$\frac{n}{10}$	100	400	1.0440	88.2	0.1651	133.1	0.5236
	3	60	..	..	....	..	...	...	1.0371	38.1	2×(0.1211)	68.19	0.9080
	4	75	..	..	....	..	...	...	1.0376	33.95	2×(0.1319)	59.95	0.9745
	5	90	..	..	....	..	...	...	1.0406	34.7	2×(0.1388)	56.75	0.9526
25	1	45	65	2	$H_2C_2O_4$	$\frac{n}{10}$	200	300	1.0414	99.7	0.0966	159.9	0.3240
	2	90	..	..	....	..	...	...	1.0448	85.6	0.1799	126.9	0.5611
	3	135	..	..	....	..	...	...	1.0452	67.0	2×(0.1265)	98.42	0.7791
	4	180	..	..	....	..	...	...	1.0458	55.3	2×(0.1401)	80.17	0.8525
	5	225	..	..	....	..	...	...	1.0455	47.7	2×(0.1483)	69.61	0.9088
26	1	30	65	2	H_2SO_4	$\frac{n}{10}$	100	400	1.0447	110.9	0.0869	164.7	0.2760
	2	62	..	..	....	..	...	...	1.0466	89.3	2×(0.0821)	127.3	0.5480
	3	90	..	..	....	..	...	...	1.0478	74.2	2×(0.1227)	103.6	0.7144
	4	120	..	..	....	..	...	...	1.0500	63.1	2×(0.1475)	83.79	0.8206
	5	150	..	..	....	..	...	...	1.0525	56.4	2×(0.1614)	70.96	0.8848
27	1	10	60	4	HCl	$\frac{n}{10}$	50	450	1.0430	95.2	0.1281	147.0	0.4144
	2	20	..	..	....	..	...	...	1.0430	60.85	2×(0.1196)	93.97	0.7738
	3	30	..	..	....	..	...	...	1.0430	42.7	2×(0.1414)	65.94	0.9162
	4	45	..	..	....	..	...	...	1.0430	35.3	2×(0.1466)	54.51	0.9506
	5	60	..	..	....	..	...	...	1.0430	34.8	2×(0.1533)	53.70	0.9968
33	1	10	60	4	HCl	$\frac{n}{10}$	100	400	1.0426	60.8	0.2351	94.77	0.7754
	2	15	..	..	....	..	...	...	1.0426	41.4	0.2833	64.54	0.9378
	3	20	..	..	....	..	...	...	1.0423	35.4	0.2919	55.58	0.9736
34	1	10	60	3	HCl	$\frac{n}{10}$	200	300	1.0435	56.4	0.2532	86.10	0.8143
35	1	90	60	1	HCl	$\frac{n}{10}$	100	400	1.0381	87.6	0.0992	152.7	0.3616
	2	180	..	..	....	..	...	...	1.0391	66.5	0.1887	112.9	0.6751
	3	225	..	..	....	..	...	...	1.0403	49.5	0.2525	81.56	0.8831
39	2	90	60	4	HCl	$\frac{n}{10}$	50	450	1.0384	39.7	0.2621	53.01	0.9607
	3	120	..	..					1.0378	30.4	0.2628	53.40	0.9779

The results point to the remarkable fact that the cupric reducing power of the total product bears a constant relation to the specific rotatory power, even when the starch is hydrolyzed under widely varying conditions. Hence, given the one, the value of the other can be calculated. To a rotation of about 90°, the plotted results outline with extraordinary exactness the arc of a circle, the equation of which is very nearly

$$x^2 + y^2 - 758x + 772.4y = 0,$$

which exactly intercepts the "zero" and "hundred" points at 195 and 53.5, respectively. The upper part of the curve is not so well defined, the results showing more discrepancy at the high conversion stages. This may be due to some decomposition, and the formation of "reversion" products as stated by Wohl,[1] Maercker, Ost, and others. Wohl's figures show the maximum amount of dextrose possible to be 92.7 per cent. of the theoretical quantity. Others give 96 to 97 per cent., the missing dextrose being supposed to be converted into dextrin-like bodies identical with those variously described as "gallisin," "isomaltose," etc. We have experimented but little along this line, having made but one hydrolysis with this special object, using $\frac{N}{100}$ hydrochloric acid at four atmospheres pressure, with the following results:

Time of cooking.	$[\alpha]_D$.
60 minutes	55.24
90 minutes	53.09
120 minutes	53.40
150 minutes	54.42

While several of our own results at the low rotations show a cupric reducing power of only about 96 per cent. of that of pure dextrose, we do not think that we are justified in arriving at any definite conclusion with the data at hand.

That the solutions begin to color considerably at rotations beyond 90° is, moreover, a strong indication of such decomposition. On the other hand, this accounts for much of the discrepancy of the plot at this part of the curve, as it is exceedingly difficult to get accurate readings on the saccharimeter of these highly colored solutions. Obviously, too, slight errors in the readings affect the calculations of the rotatory power the most at these lowest rotations.

[1] Ber. der chem. Ges., 23, 2101.

Quite as noteworthy are the curves[1] plotted by taking the values of maltose, dextrin, and dextrose as computed for every five degrees of rotation from the values of K, as given by this curve.

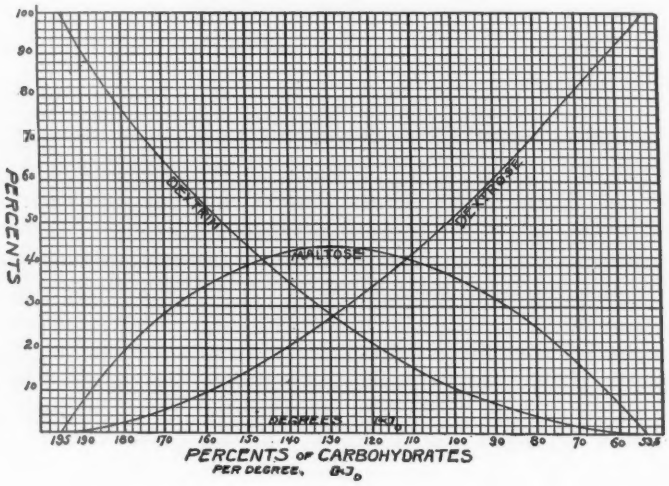

FIG. 3.

In this work we have figured constants for solids estimated from the specific gravities of solutions by the factor 386, and calculated percentages by the well-known equations:

$$g + m + d = 1.00$$
$$g + 0.61m = K$$
$$195d + 135.2m + 53.5g = a$$

Where g is per cent. dextrose,
m is per cent. maltose,
and d is per cent. dextrin.

$$\text{Hence } m = \frac{a + 141.5K - 195}{26.52}.$$

Examining these curves we see that the dextrin starting from the maximum of 100 per cent. gradually falls to zero near the rotation

[1] See Figure 3.

corresponding to dextrose, while the maltose gradually rises, reaches a maximum percentage of 46.2 at about 129° rotation, corresponding to the usual state of conversion of commercial glucose, and then falls, disappearing at 53.5°. The dextrose, on the contrary, steadily mounts to 100 per cent. It will be noted, too, that at the point of maximum maltose the dextrin and dextrose, as shown by the intersection of the curves, are present in equal quantity.

Tests with phenylhydrazin acetate show the presence of the dextrose distinctly at about 185°, and we had hoped to prove the gradual rise of the dextrose percentage by means of the dextrosazon. While copious precipitates of this beautiful compound were obtained, any attempt of ours to isolate it in anything like quantitative amounts proved a failure, even in solutions containing a known amount of pure dextrose. We hope to take this up more fully in a later investigation.

We have also calculated a table (Table C) from the curves, giving the value of maltose, dextrose, and dextrin within .1 per cent. for successive stages of acid hydrolysis represented by each degree of rotation between 195 and 53.5. This table, calculated for the factor 386, makes no allowance for possible decomposition of high-converted products.

TABLE C.

CALCULATED VALUES OF CUPRIC REDUCING POWERS AND PARTS OF MALTOSE, DEXTROSE, AND DEXTRIN PER UNIT OF CARBOHYDRATE FOR EACH DEGREE OF ROTATION OF A NORMALLY HYDROLYZED STARCH SOLUTION.

$[\alpha]^{20}_{D\ 386.}$	$K_{386.}$	$m_{386.}$	$g_{386.}$	$d_{386.}$
195	0.000	0.000	0.000	1.000
194	0.011	0.017	0.001	0.982
193	0.022	0.038	0.001	0.966
192	0.032	0.052	0.001	0.947
191	0.041	0.068	0.002	0.930
190	0.051	0.084	0.002	0.914
189	0.061	0.098	0.002	0.900
188	0.071	0.114	0.003	0.883
187	0.081	0.128	0.003	0.869
186	0.090	0.143	0.005	0.852
185	0.100	0.157	0.005	0.838
184	0.109	0.170	0.008	0.822
183	0.118	0.183	0.010	0.807
182	0.127	0.195	0.012	0.793
181	0.137	0.207	0.014	0.779
180	0.146	0.219	0.016	0.765
179	0.155	0.227	0.019	0.754
178	0.164	0.237	0.022	0.741
177	0.173	0.247	0.024	0.729
176	0.182	0.257	0.027	0.716
175	0.191	0.266	0.031	0.708
174	0.199	0.274	0.034	0.692
173	0.207	0.282	0.038	0.680
172	0.216	0.290	0.042	0.668
171	0.224	0.298	0.046	0.656
170	0.233	0.305	0.050	0.645
169	0.242	0.312	0.053	0.635
168	0.251	0.318	0.056	0.625
167	0.259	0.325	0.060	0.615
166	0.267	0.331	0.064	0.605
165	0.275	0.337	0.068	0.595
164	0.283	0.343	0.073	0.584
163	0.292	0.350	0.076	0.572
162	0.300	0.356	0.083	0.561
161	0.308	0.362	0.088	0.550
160	0.316	0.367	0.093	0.540
159	0.324	0.374	0.098	0.528
158	0.332	0.381	0.102	0.517
157	0.340	0.387	0.106	0.507
156	0.348	0.392	0.110	0.498
155	0.356	0.397	0.115	0.488
154	0.365	0.402	0.120	0.478
153	0.373	0.407	0.125	0.468
152	0.381	0.412	0.130	0.458
151	0.389	0.414	0.135	0.451
150	0.397	0.421	0.140	0.439
149	0.404	0.425	0.146	0.429
148	0.412	0.429	0.152	0.419
147	0.419	0.432	0.158	0.410
146	0.427	0.434	0.163	0.403
145	0.435	0.436	0.169	0.395
144	0.442	0.439	0.175	0.386
143	0.450	0.442	0.183	0.375

TABLE C. — *Continued.*

$[a]^{20}_{D\,386.}$	$K_{386.}$	$m_{386.}$	$\varepsilon_{386.}$	$d_{386.}$
142	0.458	0.445	0.188	0.367
141	0.465	0.448	0 193	0.359
140	0.473	0.450	0.199	0.351
139	0.481	0.452	0.206	0.342
138	0.488	0.454	0.212	0.334
137	0.496	0.456	0.219	0.325
136	0.503	0.458	0.224	0.318
135	0.510	0.459	0.230	0.311
134	0.517	0.459	0.237	0.304
133	0.524	0.460	0.244	0.296
132	0.531	0.460	0.250	0.290
131	0.538	0.461	0.257	0.282
130	0.546	0.462	0.264	0.274
129	0.553	0.462	0.272	0.266
128	0.560	0.462	0.279	0.258
127	0.567	0.461	0 284	0.253
126	0.574	0.460	0.294	0.246
125	0.580	0.460	0.301	0.239
124	0.588	0.459	0.308	0.233
123	0.595	0.458	0.315	0.227
122	0.602	0.456	0.323	0.221
121	0 608	0.455	0.331	0.214
120	0.614	0.453	0 338	0.209
119	0.621	0.451	0.346	0.203
118	0.628	0.450	0.354	0.196
117	0.635	0.448	0.361	0.191
116	0.642	0.446	0.369	0.185
115	0.649	0.444	0.377	0.178
114	0 656	0.442	0.387	0.171
113	0.663	0.439	0.395	0.166
112	0.669	0.436	0.403	0.161
111	0.675	0.433	0.411	0.156
110	0.681	0.429	0 420	0.152
109	0.687	0.425	0.428	0.147
108	0.694	0.421	0.436	0.143
107	0.700	0.418	0.445	0.137
106	0.707	0.414	0.453	0.133
105	0.713	0.411	0.462	0.127
104	0 719	0.407	0.471	0.122
103	0.725	0.402	0 480	0.118
102	0.732	0.398	0.489	0.113
101	0.738	0.393	0.498	0.109
100	0.744	0 389	0.508	0.103
99	0.750	0.384	0.518	0 098
98	0.757	0.380	0.527	0.093
97	0.763	0.374	0.536	0.090
96	0.769	0.368	0 545	0.087
95	0.775	0.362	0.554	0.084
94	0.781	0.357	0.563	0.080
93	0 787	0.352	0.572	0.076
92	0.793	0.347	0.581	0.072
91	0.799	0.342	0.591	0.068
90	0 805	0.336	0 600	0.064
89	0.810	0 329	0.610	0 061
88	0 816	0.322	0.620	0 058
87	0.822	0.315	0 630	0.055
86	0.828	0.308	0.640	0.052

TABLE C. — *Concluded.*

$[a]^{20}_{D\,386.}$	$K_{386.}$	$m_{386.}$	$g_{386.}$	$d_{386.}$
85	0.834	0.302	0.650	0.048
84	0.839	0.294	0.660	0.044
83	0.844	0.287	0.670	0.043
82	0.850	0.279	0.680	0.041
81	0.856	0.272	0.690	0.038
80	0.862	0.264	0.701	0.035
79	0.867	0.256	0.712	0.032
78	0.872	0.247	0.722	0.031
77	0.878	0.237	0.733	0.030
76	0.884	0.228	0.744	0.028
75	0.889	0.219	0.755	0.026
74	0.895	0.210	0.766	0.024
73	0.901	0.199	0.778	0.023
72	0.906	0.189	0.789	0.022
71	0.911	0.179	0.791	0.020
70	0.916	0.170	0.811	0.018
69	0.921	0.159	0.824	0.017
68	0.926	0.149	0.835	0.016
67	0.932	0 139	0.846	0.015
66	0.937	0.130	0.856	0.014
65	0.942	0.121	0.867	0.012
64	0.947	0.110	0.879	0.011
63	0.952	0.099	0.880	0.011
62	0.957	0.088	0.902	0.010
61	0.962	0.078	0.914	0.008
60	0.967	0.068	0.926	0.006
59	0.972	0.057	0.937	0.006
58	0.977	0.047	0.948	0.005
57	0.982	0.036	0.960	0.004
56	0.987	0.025	0.971	0.004
55	0.992	0.015	0.982	0.003
54	0.997	0.005	0.993	0.002
53.5	1.000	0.000	1.000	0.000

It would seem obvious that we are now prepared to determine whether a sample of glucose is a product of one hydrolysis or is a mixture of two separately converted products, by comparison of the actual analytical results with those calculated from the rotatory power.

For testing this method we have made a few analyses of commercial glucoses obtained in open market.

In the manufacture of glucose syrup all the starch is not hydrolyzed under strictly the same conditions, as the factory practice is to pump the starch into the converter which is under steam pressure and already contains the hydrolyzing acid. As the filling of a converter takes about one-third of the total time of cooking, it is clear that there is a radical difference in the time of hydrolysis of different portions of starch. Nevertheless, we have found that samples known

to have been made under these conditions conform to the laws of our curve, and the evidence seems strong that those which depart widely from these conditions are mechanical mixtures.

The following determinations of four samples of commercial glucose, giving the cupric reducing power as found and as calculated for the corresponding rotation, will illustrate the method:

Sample.	a_{D386}.	K_{386} (obtained.)	K_{386} (calculated.)
I. C. Pope Co. (J)	131.7	0.520	0.537
II. C. Pope Co. (M)	125.4	0.578	0.578
III. Rockford Co.	141.9	0.454	0.457
IV. Chicago Co.	137.2	0.505	0.495

Evidently II and III are normally hydrolyzed. IV is possibly a mixture, while I is undoubtedly so. As this latter is a sample of jelly goods which in factory practice are often made by mixing two lots, our conclusion is strengthened.

From the results as a whole we have concluded that the evidence is strong: (1) That in any homogeneous acid-converted starch product, irrespective of the conditions of hydrolysis, the specific rotatory power always represents the same chemical composition.

(2) That but three simple carbohydrates,[1] possibly in molecular aggregates, exist in the solution of a starch product hydrolyzed by acids.

Determination of the Conversion of Commercial Glucose.

In the manufacture of glucose it is obviously essential to have a rapid means of determining the degree of conversion of the starch during the cooking process. The usual factory practice is to control the conversion by means of iodine color tests. These tests are usually made by adding a definite number of drops of standard iodine solution to a test-tube of the cooled glucose liquor. The tint at which

[1] Leaving out of consideration the possible small amounts of products formed by reversion.

the conversion is considered complete varies in general practice from that corresponding to $[a]_D = 128$ to $[a]_D = 135$, the variation being even greater in some cases, depending on the ideas of the manufacturer, and the grade of goods desired.

By daily practice workmen become quite expert in making these iodine tints, which are usually carried out by crude methods and read off without comparison with any standard. Nevertheless, the product, when examined by more refined laboratory processes, shows wide variations from day to day, which does not appear surprising when we examine into the errors of such color tests.

Assuming that the test is carried out under uniform conditions of concentration and proportion of reagent to liquor to be tested, which is by no means always the case, the other conditions affecting the color are (1) temperature, (2) turbidity, and (3) illumination.

Uniform temperature can be obtained easily by some simple cooling device, as a stream of running water.

The acid converter liquors are always turbid when tested, as filtration in this rapid testing is impracticable. The turbidity, however, is fairly constant. It is the third condition, that of illumination, which is constantly variable, and which gives rise to the greatest error. This source of error can be largely eliminated by the use of a comparison standard, prepared of the same volume as that used in the color test, and hermetically sealed in a glass tube of the standard size used in testing. Mixtures of solutions of iron salts with finely pulverized glass, giving the requisite turbidity when shaken, can be easily made to exactly match the iodine tint, and will preserve their intensity indefinitely. When properly adjusted by means of polariscopic tests, such standards have served well to fix the point of conversion within narrow limits, and have done much to insure a uniform product.

It is of course important that there should be in the hands of the chemist or superintendent of the works a much more exact means of testing the degree of conversion. This is most naturally accomplished by determining the specific rotatory power.

We have arranged a table for quickly calculating specific rotatory power, and found it so useful that we venture to publish it. The following simple calculation will sufficiently explain the principles on which the table has been worked out:

TABLE D.

TABLE FOR DETERMINING SPECIFIC ROTATORY POWER OF SOLUTIONS OF 7.50°–10° BRIX BY READING OF VENTZKE SACCHARIMETER.

Brix.	Specific gravity.	W = gram per 100 cc.	Log $\frac{17.20}{W}$.	Brix.	Specific gravity.	W = gram per 100 cc.	Log $\frac{17.20}{W}$.
7.50	1.0298	7.724	0.3477	8.80	1.0352	9.110	0.2760
7.55	1.0300	7.777	0.3447	8.85	1.0354	9.163	0.2735
7.60	1.0302	7.829	0.3418	8.90	1.0356	9.217	0.2709
7.65	1.0304	7.883	0.3388	8.95	1.0358	9.270	0.2684
7.70	1.0306	7.936	0.3359	9.00	1.0360	9.324	0.2657
7.75	1.0308	7.989	0.3330	9.05	1.0362	9.378	0.2634
7.80	1.0310	8.042	0.3301	9.10	1.0364	9.430	0.2610
7.85	1.0312	8.096	0.3272	9.15	1.0366	9.484	0.2585
7.90	1.0315	8.149	0.3244	9.20	1.0368	9.538	0.2560
7.95	1.0317	8.202	0.3216	9.25	1.0370	9.592	0.2536
8.00	1.0319	8.255	0.3187	9.30	1.0372	9.646	0.2510
8.05	1.0321	8.308	0.3160	9.35	1.0374	9.690	0.2488
8.10	1.0323	8.361	0.3132	9.40	1.0376	9.753	0.2464
8.15	1.0325	8.415	0.3104	9.45	1.0378	9.807	0.2440
8.20	1.0327	8.468	0.3077	9.50	1.0381	9.862	0.2415
8.25	1.0329	8.522	0.3050	9.55	1.0383	9.916	0.2391
8.30	1.0331	8.575	0.3022	9.60	1.0385	9.970	0.2368
8.35	1.0333	8.629	0.2995	9.65	1.0387	10.023	0.2346
8.40	1.0335	8.682	0.2969	9.70	1.0389	10.077	0.2323
8.45	1.0337	8.735	0.2943	9.75	1.0391	10.130	0.2300
8.50	1.0339	8.788	0.2916	9.80	1.0393	10.185	0.2277
8.55	1.0341	8.842	0.2889	9.85	1.0395	10.239	0.2252
8.60	1.0343	8.895	0.2864	9.90	1.0397	10.293	0.2231
8.65	1.0345	8.949	0.2838	9.95	1.0399	10.347	0.2207
8.70	1.0347	9.002	0.2812	10.00	1.0401	10.401	0.2185
8.75	1.0350	9.056	0.2786	....	....	....	....

Taking the usual formula for the specific rotatory power, $a = \frac{av}{lw}$, where a is the angle of rotation of w grams of the active substance in v cc. of solution observed through a column l decimeters long. If we make $a = a$, it is plain w is the weight of substance under standard conditions which will give a direct reading of the specific rotatory power without calculation. In an instrument reading in angular degrees under the usual conditions of $v = 100$ and $l = 2$, w is therefore 50 g.

If a is the reading of a saccharimeter with the Ventzke scale, $w = 50 \times 0.344 = 17.20$, and the specific rotatory power of any solution of known concentration of an optically active substance will be

$\frac{17.2a}{w}$. The easiest way of finding the concentration of glucose solutions with sufficient exactness for this work is by the Brix (or Balling) hydrometer, as this instrument is now made of great accuracy.

Brix hydrometers are carried in regular stock of the larger houses dealing in chemical apparatus for brewers and sugar manufacturers, with scales having a range of about five degrees and easily read to 0.05 per cent. Thermometers are attached having corrections for temperature marked on the scale. Concentrations of about 10 per cent. are most convenient for polarizing; hence a spindle will be needed reading from 5 to 10 per cent.

The method of determining rotatory powers is as follows: The glucose is diluted to an approximately 10 per cent. solution. An exact Brix (or Balling) reading is taken, corrected for standard temperature, and the solution polarized in a 200 mm. tube in any saccharimeter with the Ventzke scale. The logarithm of the factor $\frac{17.20}{w}$ corresponding to the Brix reading is then found in the table. Therefore, the calculation which is, $\log [a]_D = \log \frac{17.20}{w} + \log a$, simply requires finding the logarithm of the saccharimeter reading, and the number corresponding to the sum of this, and the logarithm given in the table. This number is the required specific rotatory power.[1]

Thus a solution of 7.85 Brix having a reading of 51.7°, Ventzke, has the rotatory power of its anhydrous carbohydrates determined as follows:

By the table, the corresponding logarithmic factor is 0.3272.

$$\begin{aligned} \text{Log } 51.7 &= 1.7135 \\ \text{Factor} \quad & \underline{0.3272} \\ & 2.0407 = \log 109.8, \end{aligned}$$

which is the required rotatory power.

In this calculation no correction is made for ash, which, as a rule, does not affect the results appreciably.

The errors due to the slight variations in the concentration of the solutions used and changes in the temperature of the laboratory are

[1] Obviously a table made on the scheme of the well-known Schmitz table for cane-sugar syrups would do away with all calculation. Such a table is, however, rather bulky for insertion here.

too small to be taken into consideration in factory work or in general commercial analysis. The method in practice is quite as rapid as the "quotient of purity" determination of cane-sugar syrups. We suggest that this, or some similar scheme, be uniformly used for expressing the results of all polarimetric investigations of honeys, syrups, and similar indeterminate mixtures of carbohydrates met with in commercial analysis, instead of merely giving the polarizations, or the specific rotatory powers referred to the weights of the samples. The advantages are obvious. Such analytical results would be close approximations to the exact specific rotatory powers of the mixed anhydrous carbohydrates, and would be convenient of interpretation by inspection as being directly comparable on what is, for all practical purposes, an absolute standard, and the one used in all strictly scientific work of the kind.

The Speed of the Hydrolysis of Starch by Acids.[1]

The laws of the speed of hydrolysis of the carbohydrates with the exception of that of cane-sugar have been but little studied. Solomon[2] has collected some data on the action of various acids at boiling temperature. Welhelmy[3] showed in the case of the catalytic action of hydrochloric acid on cane-sugar, that if the amount of acid and the temperature remained constant the rate of the inversion at any specified moment is proportional to the amount of unchanged sugar present at that moment.

That is, if A_0 represent the amount of sugar originally present, x the amount of this sugar changed over in any period of time t, and c the reaction-constant, we have $\frac{dx}{dt} = c\,(A_0 - x)$.

The relative values of the constant c, of the various acids in their action on cane-sugar, have been determined by several observers, notably Ostwald,[4] who has compared, by means of their constants, the relative effect of chemically equivalent quantities of a large number of acids, taking the constant of hydrochloric acid as a standard with the arbitrary value of 100.

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[1] We are greatly indebted to Professor A. A. Noyes, of this department, for valuable aid in calculating the results of this work on speed of hydrolysis.

[2] J. prakt. Chem. (2), 28.

[3] Ber. d. Chem. Ges., 18, 2211.

[4] J. prakt. Chem., 401 (1884).

Recent work shows that acids act on salicin,[1] one of the glucosides, in a manner analogous to that of cane-sugar, the speed of hydrolysis of this body by the different acids bearing the same relation to hydrochloric acid.

The observations noted above suggested the possibility that in the hydrolysis of starch the acids would show the same proportional speed of reaction. This is an especially interesting problem, because the starch molecule is exceedingly complicated, the molecular weight being undoubtedly very high. Starch hydrolysis, however, must be considered as somewhat different from that of cane-sugar or salicin. While these are easily soluble in cold water, starch is totally insoluble at ordinary room temperature. On the other hand, amylodextrin, the product of decomposition of starch by boiling water, is somewhat soluble in cold water, its solubility increasing with rise of temperature.

As by the customary procedure in determining speed of hydrolysis, it would be necessary to ascertain the exact moment when all the starch has been converted into the soluble form, a point not conveniently determined, we have adopted a method of measurement based on the following principles:

The conversion products of starch, with the possible exception of those of very high rotatory power, are easily soluble in water, and can be looked upon as mixtures of maltose, dextrose, and dextrin.

The starch first changes to amylodextrin. The hydrolysis then proceeds by successive stages through the so-called maltodextrin, maltose, and dextrose. "Reversion," so-called, may take place to some extent, a small amount of the dextrose forming dextrin-like bodies, "gallisin," "isomaltose," etc., but this point is not considered in this work. The dextrin may, therefore, be looked upon as the original substance hydrolyzed, and maltose and dextrose as successive products of the reaction.

Further, we have shown that, whatever the condition of hydrolysis by acids, the specific rotatory power of any conversion product corresponds to a definite chemical composition, tables for determining which we have constructed.

Thus, for instance, a conversion product of 160° has been proved to contain 54.0 per cent. dextrin, the remainder being maltose and dextrose.

Hence, the time of taking any sample after the contents of the

[1] Noyes and Hall; Ztschr. phys. Chem., 240 (1895).

autoclave have acquired constant temperature, which requires about ten minutes, can be taken as the initial point for determining speed of hydrolysis, and all subsequent samples referred to this, as it is obvious that in any sample we can ascertain the dextrin unacted upon at that stage of the hydrolysis. The same holds true of maltose.

We have to deal with two reactions, the first being the hydrolysis of dextrin to maltose.

If A_0 is the amount of dextrin at the initial point taken, $A_0 - x$, the amount remaining at any time, t, and c the constant depending on conditions of hydrolysis, we get, $\frac{dx}{dt} = c\,(A_0 - x)$.

This, on integrating, gives nat. log $\frac{A_0}{A - x} = ct$, or $\frac{1}{t}$ nat. log $\frac{A_0}{A_0 - x} = c$, which is the general equation of a first-order reaction. The second decomposition is that in which maltose is hydrolyzed to dextrose, and is peculiar in so far as it proceeds simultaneously with that by which the maltose is formed. As a result of the hydrolysis of the dextrin, the maltose increases rapidly to a maximum of 46.2 per cent. at a rotation of 129°. It then gradually diminishes, while the dextrose percentage always increases.

Consequently, the equation expressing accurately the rate of change in the total amount of maltose present is quite complicated, and we have, therefore, used an approximate formula, which is sufficiently exact for the work in hand. The formula is derived from the exact differential equation

$$\frac{dD}{dt} = c_2 M,$$

which states that the amount of dextrose formed at each moment is proportional to the amount of maltose present by replacing the differential quantities by finite differences, which in applications of the formula must of course be taken small. In the place of M the average amount of maltose present during the interval of time considered is also substituted. That is, if M_1 and M_2 are the amounts of maltose present at the time, t_1 and t_2, and D_1 and D_2 the amounts of dextrose present at these same times, and c_2 is the reaction constant, we get as a result of the above-mentioned substitutions:

$$D_2 - D_1 = c_2 \frac{M_1 + M_2}{2} (t_2 - t_1),$$

or,

$$\left(\frac{1}{t_2 - t_1}\right) \left(\frac{D_2 - D_1}{\frac{M_1 + M_2}{2}}\right) = c_2.$$

The results are contained in the following tables:

TABLE E.

SPEED OF HYDROLYSIS OF STARCH.

Hydrochloric acid 0.02 normal at 2 A $t = 135°$ C.

$t_0 = 20$; $[a]^{20}_{D\,386} = 161$; $A_0 = 55.0$.

Time t. (Minutes.)	$[a]^{20}_{D\,386}$.	$A_0 - x$.	$\log^1 \frac{A_0}{A_0 - x}$.	C_1.	$\frac{D_2 - D_1}{\frac{m_1 + m_2}{2}}$	C_2.
10	137	32.5	.2285	.0219	.3286	.0329
20	118	19.6	.4481	.0224	.3225	.0333
30	101	10.9	.7130	.0237	.3417	.0342
40	87	5.5	1.0000	.0225	.3816	.0382
50	76	2.8	1.2932	.0258	.4296	.0430
60	69	1.7	1.5100	.0252	.4134	.0413
70	64	1.1	1.7090	.0271	.4833	.0483

$C_1 = 0.0242$. $C_2 = 0.0387$.

Sulphuric acid 0.02 normal at 2 A $t = 135°$ C.

$t_0 = 20$; $[a]^{20}_{D\,386} = 177°$; $A_0 = 72.9$.

10	163	57.2	.1053	.0105	.1809	.0181
20	152	45.8	.2018	.0109	.1365	.0136
30	140	35.1	.3174	.0105	.1601	.0160
40	129	26.6	.4378	.0109	.1601	.0160
60	109	14.7	.7954	.0132	.3518	.0171
80	90	6.4	1.0565	.0132	.4581	.0229
100	77	3.0	1.3856	.0138	.4641	.0232
120	66	1.4	1.7166	.0143	.6524	.0326

$C_1 = .0121$. $C_2 = .0199$.

[1] As is customary, common logarithms are used in these calculations.

TABLE E.— *Continued.*

Oxalic acid 0.04 normal at 2 A $t = 135°$ C.

$t_0 = 20$; $[a]^{20}_{D\,386} = 180°$; $A_0 = 76.5$.

Time t. (Minutes.)	$[a]^{20}_{D\,386}$.	$A_0 - x$.	$\log \frac{A_0}{A_0 - x}$.	C_1.	$\frac{D_2 - D_1}{\frac{m_1 + m_2}{2}}$	C_2.
20	157	50.7	.1787	.00894	.2970	.0148
40	137	32.5	.3718	.00929	.2684	.0134
60	120	20.9	.5636	.00939	.2617	.0138
80	106	13.3	.7598	.00949	.2653	.0137
100	93	7.6	1.0029	.01003	.3099	.0158
120	82	4.1	1.2709	.01059	.3423	.0171
140	73	2.3	1.5220	.01087	.4101	.0205

$C_1 = .00980$. $C_2 = .00156$.

Sulphuric acid 0.02 normal at 2 A $t = 135°$.

$t_0 = 50$; $[a]^{20}_{D\,386} = 187°$; $A_0 = 86.9$.

50	179	75.4	.0616	.00123	.0901	.00180
100	172	66.8	.1142	.00114	.0889	.00177
150	165	59.5	.1645	.00109	.0829	.00165
200	159	52.8	.2164	.00108	.0843	.00168
250	151	45.1	.2848	.00113	.0939	.00187
300	144	38.6	.3524	.00117	.0938	.00187
350	137	32.5	.4271	.00122	.0983	.00196
400	131	28.2	.4888	.00122	.0828	.00185

$C_1 = .00116$. $C_2 = .00181$.

Acetic acid 0.5 normal at 2 A $t = 135°$ C.

$t_0 = 50$; $[a]^{20}_{D\,386} = 170°$; $A_0 = 64.5$.

50	143	37.5	.2356	.00470	.3561	.00712
100	121	21.4	.4792	.00479	.3225	.00645
150	103	11.8	.7377	.00491	.3058	.00611
200	86	5.2	1.1936	.00597	.4404	.00881
250	74	2.4	1.4294	.00571	.4623	.00924

$C_1 = .00522$. $C_2 = .00755$.

TABLE E. — *Continued.*

Hydrochloric acid 0.01 normal at 1 $A\,t = 121°$ C.

$t_0 = 40$; $[a]^{20}_{D\,386} = 183°$; $A_0 = 80.7$.

Time t. (Minutes.)	$[a]^{20}_{D\,386}$.	$A_0 - x$.	$\log \frac{A_0}{A_0 - x}$	C_1.	$\frac{D_2 - D_1}{\frac{m_1 + m_2}{2}}$	C_2.
40	168	62.5	.1110	.00277	.1837	.00459
70	158	51.7	.1934	.00276	.1314	.00438
100	149	42.9	.2744	.00274	.1091	.00364
140	137	32.5	.3950	.00282	.1657	.00414
180	126	24.6	.5160	.00287	.1637	.00409
200	120	20.9	.5860	.00293	.0984	.00492
250	107	13.7	.7702	.00308	.2457	.00491

$C_1 = .00285$. $C_2 = .00438$.

Hydrochloric acid 0.01 normal at 2 $A\,t = 135°$ C.

$t_0 = 20$; $[a]^{20}_{D\,386} = 176°$; $A_0 = 71.6$.

10	162	56.1	.1059	.0106	.1827	.0183
20	148	41.9	.2327	.0116	.1758	.0176
40	128	25.8	.4433	.0111	.2850	.0143
60	110	15.2	.6731	.0110	.2845	.0142
80	93	7.6	.9741	.0127	.3530	.0172
100	81	3.8	1.2751	.0127	.3782	.0184
120	70	1.8	1.6996	.0142	.5475	.0294

$C_1 = .0120$. $C_2 = .0182$.

Hydrochloric acid 0.01 normal at 3 $A\,t = 145°$ C.

$t_0 = 10$; $[a]^{20}_{D\,386} = 174°$; $A_0 = 69.2$

5	158	51.7	.1265	.0253	.2076	.0425
10	140	35.1	.2948	.0295	.1855	.0590
15	125	23.9	.4617	.0308	.2242	.0616
20	110	15.2	.6583	.0329	.2677	.0658
30	88	5.8	1.0766	.0359	.5353	.0535
40	74	2.4	1.4599	.0365	.5489	.0549
50	65	1.2	1.7609	.0352	.6116	.0611

$C_1 = .0323$. $C_2 = .0569$.

TABLE E.— *Continued.*

Hydrochloric acid 0.01 normal at 4 $A\,t - 153°$ C.

$t_0 = 10$; $[a]^{20}_{D\,386} = 147°$; $A_0 = 41.0$.

Time t. (Minutes.)	$[a]^{20}_{D\,386}$.	$A_0 - x$.	$\log \frac{A_0}{A_0 - x}$.	C_1.	$\frac{D_2 - D_1}{\frac{m_1 + m}{2}}$	C_2.
5	117	19.1	.3318	.0664	.4613	.0923
10	96	8.7	.6733	.0673	.4509	.0902
15	79	3.2	1.1077	.0738	.5351	.1072
20	68	1.6	1.4087	.0704	.5580	.1160
25	61	0.8	1.7097	.0684	.6960	.1392
30	57	0.4	2.0107	.0670	.8847	.1769
				$C_1 = .0688$.		$C_2 = .1203$.

Hydrochloric acid 0.04 normal at 3 $A\,t = 145°$ C.

$t_0 = 5$; $[a]^{20}_{D\,386} = 150°$; $A_0 = 43.9$.

3	115	17.8	0.3921	.1307	.5479	.1826
5	95	8.4	0.7182	.1436	.4329	.2165
7	80	3.5	1.0984	.1569	.5017	.2509
10	66	1.4	1.4964	.1496	.7866	.2622
13	58	0.5	1.9435	.1495	1.0400	.3467
15	56	0.4	2.0404	.1360	.6389	.3195
				$C_1 = .1444$.		$C_2 = .2631$.

Hydrochloric acid 0.02 normal at 3 $A\,t = 145°$ C.

$t_0 = 10$; $[a]^{20}_{D\,386} = 148°$; $A_0 = 41.9$.

5	116	18.5	0.3550	.0710	.4961	.0992
10	96	8.7	0.6827	.0683	.4903	.0981
15	80	3.5	1.0781	.0672	.4937	.0987
20	69	1.7	1.3918	.0696	.5343	.1069
25	61	0.8	1.7291	.0692	.7003	.1400
30	56	0.4	2.0201	.0673	1.1070	.2214
				$C_1 = .0688$.		$C_2 = .1274$.

TABLE E. — *Concluded.*

Hydrochloric acid 0.01 normal at 3 $At = 145°$ C.

$t_0 = 5$; $[a]^{20}_{D\,386} = 174°$; $A_0 = 69.2$.

Time t. (Minutes.)	$[a]^{20}_{D\,386}$.	$A_0 - x$.	$\log \frac{A_0}{A_0 - x}$.	C_1	$\frac{D_2 - D_1}{\frac{m_1 + m_2}{2}}$	C_2.
5	158	51.7	0.1265	.0253	.2076	.0415
10	140	35.1	0.2948	.0295	.2328	.0465
15	125	23.9	0.4617	.0307	.2294	.0459
20	110	15.2	0.6583	.0329	.2677	.0535
30	88	5.8	1.0767	.0359	.5326	.0533
40	74	2.4	1.4599	.0365	.5489	.0549
50	65	1.2	1.7609	.0332	.6102	.0610
				$C_1 = .0320$.		$C_2 = .0424$.

Hydrochloric acid 0.005 normal at 3 $At = 145°$ C.

$t_0 = 20$; $[a]^{20}_{D\,386} = 172°$; $A_0 = 66.8$.

20	142	36.7	0.2601	.00130	.3973	.00189
40	113	16.6	0.6047	.00151	.2418	.00121
60	91	6.7	1.0087	.00168	.5020	.00251
80	77	3.0	1.3577	.00169	.4559	.00223
100	66	1.4	1.6787	.00168	.6701	.00335
120	59	0.6	2.0466	.00171	.7595	.00380
				$C_1 = .0159$.		$C_2 = .02497$.

At the head of each table are given data as to the concentration and nature of the acid, the temperature corresponding to the steam pressure given in atmospheres, and $[a]^{20}_{D\,386}$ at the initial time period t_0 with the corresponding value of A_0. Time values are expressed in minutes, and the constants c_1 for the hydrolysis of dextrin, c_2 for that of maltose, are calculated according to the formulas given above.

The results show that the constants in general are satisfactory, and that, therefore, the reaction like the sucrose inversion follows the law of the first order. It will also be seen that the values c_1 are much more uniform than those of c_2, which is to be expected since c_1 is absolute, and c_2 only approximate. Deviations of c_1 may be fairly ascribed to variations in temperature, which, though slight, are significant, owing to the high temperature coefficient of the reaction.

The dextrin values in Table C are consequently correct within the limits of error of analysis. It will be seen that the values of c_2 are much more constant in those determinations in which t is larger, and the values of $[a]_D$ decrease slowly. This was to be expected from the conditions of the approximate formula given above for the decomposition of maltose, these requiring that the amount of substance changed in a period of time must be small. The question of reversion may possibly have some influence on the values of c_2, but as yet we are not prepared to express ourselves definitely on this subject.

The relative effects are shown in the following table. Table I shows the influence on the speed of hydrolysis of various acids at the same temperature, 135° C.

Table II shows the influence of temperature on the speed of hydrolysis when the same amount of acid is used.

Table III gives the influence of varying amounts of acid.

The mean value of constants is given in column II. Column III gives the relative value of the constants referred to, that of $\frac{1}{60}N$ hydrochloric acid at 135° taken as 100. Column IV gives the velocity constants determined by Ostwald[1] for cane-sugar inversion by the same acids at half-normal concentration.

TABLE I.

Acid.	Concentration.	II.	III.	IV.
Hydrochloric	0.02 N	0.0242	100	100
Sulphuric	0.02 N	0.0110	50.0	53.6
Oxalic	0.04 N	0.00980	40.8	....
(Oxalic)	(0.02 N)	(0.00249)	(20.4)	18.6
Sulphurous	0.02 N	0.00126	4.79	....
Acetic	0.5 N	0.00522	21.5	....
(Acetic)	(0.02 N)	0.00021	0.8	0.4

[1] Loc. cit.

TABLE II.

Acid.	Concentration.	Temperature.	I.	II.
Hydrochloric	0.01 N	121	0.00283	11.5
Hydrochloric	0.01 N	134	0.0120	49.7
Hydrochloric	0.01 N	145	0.0323	133.4
Hydrochloric	0.01 N	153	0.0688	284.2

TABLE III.

Acid.	Concentration.	II.	III.
Hydrochloric	0.04 N	0.1413	596.7
Hydrochloric	0.02 N	0.0678	284.3
Hydrochloric	0.01 N	0.0314	132.2
Hydrochloric	0.005 N	0.0155	65.7

It is seen that the corresponding numbers of columns III and IV agree fairly well. The relative influence of the various acids upon the hydrolysis of starch, sucrose, and salicin are, therefore, nearly identical. It should be noted, however, that the chemical activity of hydrochloric acid on starch, as in the case of salicin and cane-sugar, increases in a greater ratio than the concentration, while the electrical conductivity increases more slowly.

The influence of temperature can be explained graphically by a curve approximating a parabola. (Figure 4.)[1]

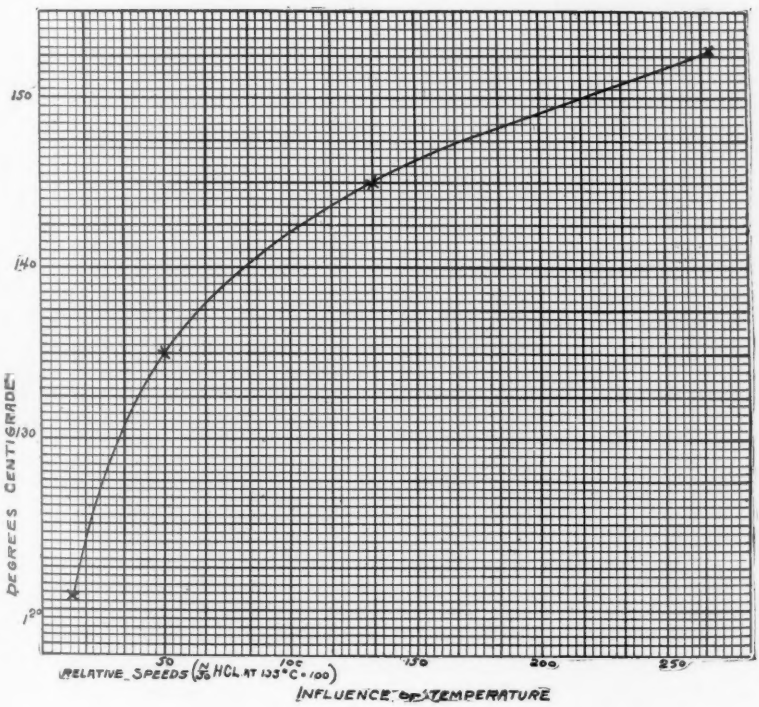

FIG. 4.

[1] Note that the last plot is accidentally displaced five divisions to the left.

Figure 5 shows the influence of the various acids.

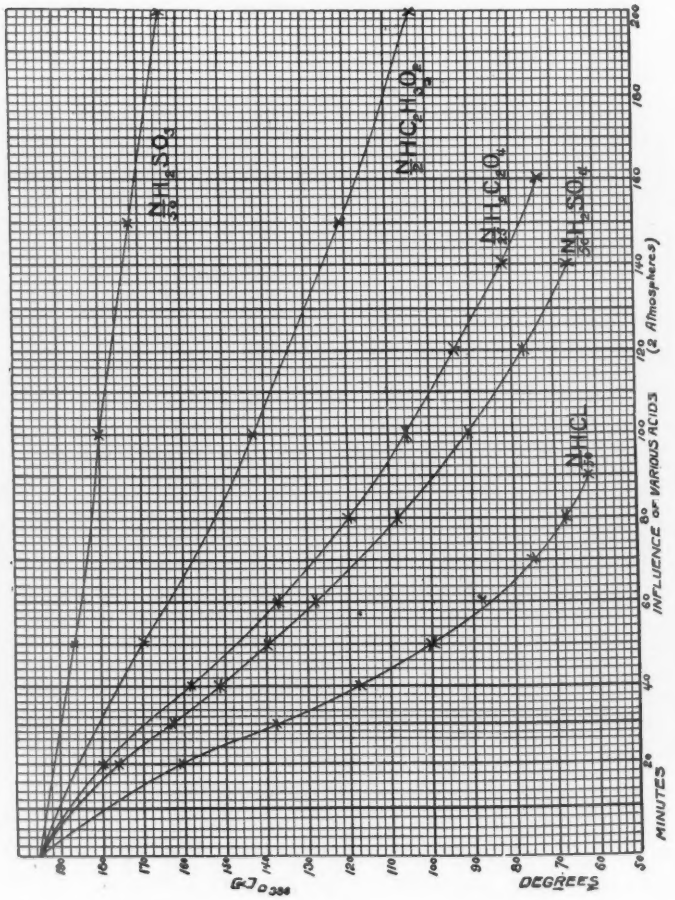

Fig. 5.

Figure 6 shows the influence of the concentration, or amount of acid used.

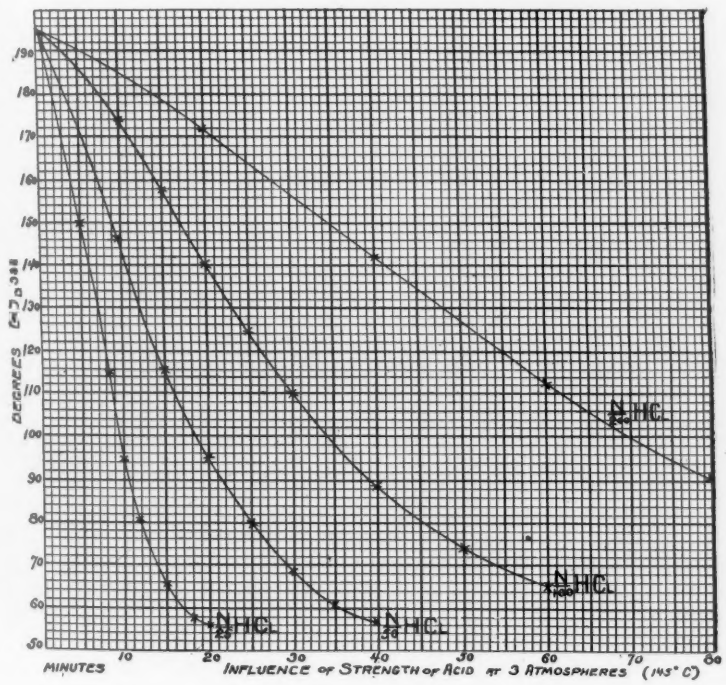

FIG. 6.

Figure 7 shows the relative curves due to temperature.

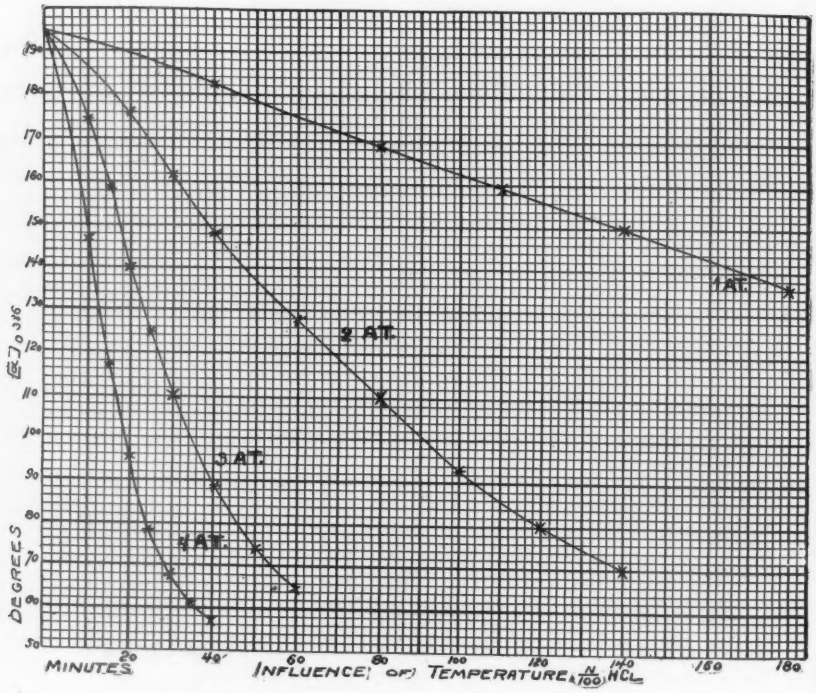

FIG. 7.

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THE DETERMINATION OF REDUCING SUGARS IN TERMS OF CUPRIC OXIDE.[1]

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It is now approximately fifty years since alkaline metallic solutions were first used in determining quantitatively the various reducing sugars. During this period of time many investigators have worked on the subject, and much has been done towards perfecting the method of analysis, so that to-day there are several admirable processes in use for the exact estimation of these carbohydrates.

The quantitative methods of determining reducing sugars may be divided into two main classes — those based upon the volumetric plan, and those which depend on a gravimetric estimation of the precipitated cuprous oxide.

Of the first class, many processes have been suggested which have met with more or less success. The volumetric methods are mainly used for factory control work, where the progress of some processes requires a rapid and fairly accurate idea of the stage of manufacture. In expert hands the volumetric methods are capable of giving excellent and concordant results, and are, therefore, used in the laboratories of many consulting chemists, and even in scientific institutions.

The main objections to the use of the volumetric methods are that each freshly prepared quantity of Fehling solution requires accurate standardization against pure sugar of the same kind as that which is undergoing analysis. Different dilutions and the time of boiling affect the results materially. The exact determination of the "end-point" also requires considerable practice and skill.

On the other hand, the Fehling liquor used in the gravimetric

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[1] Reprinted from the Journal of the American Chemical Society, **18**, No. 9, September, 1896.

processes need not be made up as accurately as is required for volumetric work. The gravimetric methods, however, ordinarily require more time. A possible loss of cuprous oxide by filtration and an incomplete oxidation to the higher oxide are also potent factors, though where the requisite degree of care is exercised these need not cause anxiety. The same statement regarding dilution and time of boiling holds true with as much force in gravimetric as in volumetric work.

The gravimetric methods are generally employed for scientific and accurate analytical work. Here the processes are comparatively few, all depending upon the oxidation of the total sugar present in an excess of the alkaline copper solution.

The tables in use for the determination of reducing sugars are mainly constructed in terms of metallic copper. As the amount of metal precipitated per gram of carbohydrate is not a constant for all dilutions of any sugar, specially constructed tables are generally employed. Several such tables have been prepared, as, for instance, Allihn's table of reduced copper for dextrose, Wein's table for maltose, and Soxhlet's table for lactose, etc.

Various modifications of the alkaline copper solutions are used for the determination of the different sugars, each requiring special treatment. Therefore a chemist in determining the amount of malt sugar in, say beer, must, if he uses Wein's table for maltose, follow exactly Wein's method for the estimation of that sugar.

Where a variety of work is carried on in a laboratory it is therefore necessary to have several different Fehling solutions on hand for each special kind of determination. If all the tables for the estimation of the different carbohydrates could have been prepared for use under uniform conditions, the existing state of affairs would be much simplified.

In order to supply this need, I have constructed such tables, using a method which I have employed for some time in determining reducing sugars. This method, proposed by O'Sullivan[1] in 1876, is used to some extent in England, but as it seems to be not generally known, I here give the procedure in detail:

To 15 cc. of the copper sulphate solution, prepared as given below, are added 15 cc. of the alkaline tartrate solution, in an Erlenmeyer flask having a capacity of from 250–300 cc. The mixture is diluted

[1] J. Chem. Soc., **2**, 130 (1876).

with 50 cc. of freshly boiled distilled water and placed in a boiling water bath for five minutes. 20 to 25 cc. accurately measured from a calibrated burette of an approximately one-half per cent. solution of the sugar to be analyzed are then run into the hot Fehling liquor, and the whole kept in the boiling water bath for from twelve to fifteen minutes. The flask is then removed from the bath, and the precipitated cuprous oxide is filtered as rapidly as possible, either through filter paper or asbestos in a Soxhlet's tube or porcelain Gooch crucible, and washed with boiling distilled water until the wash-water no longer reacts alkaline. It is ignited and weighed as cupric oxide, as described below. The corresponding amounts of dextrose, maltose, or lactose are ascertained by reference to the tables at the end of this article. It should be noted that the above directions must be closely followed. The volume of the Fehling liquor and the added sugar solution should be from 100–105 cc.

The Fehling solution used is made up according to Soxhlet's formula, with a very slight modification. 69.278 grams of pure crystallized copper sulphate, pulverized and dried between filter paper, are dissolved in distilled water. It is advantageous to add 1 cc. of strong sulphuric acid to this, as recommended by Sutton.[1] The whole is then made up to one liter with distilled water and kept in a separate bottle. The alkaline tartrate solution is made by dissolving 346 grams of crystalline Rochelle salt and 100 grams of sodium hydroxide in distilled water and making up to one liter. This is also kept in a separate bottle.

Two methods of filtration of the precipitated cuprous oxide and further treatment are generally adopted. In the first, double "washed" filter paper is used; in the other the precipitate is retained by a layer of asbestos. After washing the precipitate on the filter paper as above described, it is dried in the usual manner and ignited in a previously weighed porcelain crucible, taking care to burn the filter paper cautiously, heating for fifteen minutes to a red heat, cooling the crucible over sulphuric acid in a desiccator, and weighing as cupric oxide. Additional treatment with nitric acid has been found of no practical advantage, the results by direct ignition being very exact, providing the filter paper is slowly burned. The chief objection to the employment of filter paper to retain the precipitated cuprous oxide is that

[1] Sutton: Vol. Anal., fourth edition, 256 (1882).

some of the finely divided particles are liable to go through, thus causing low results.

As a substitute for paper, carefully selected asbestos is often used for filtering purposes. To insure a layer of asbestos which shall be kept at constant weight under the action of hot Fehling liquor, it is advantageous to boil the mineral with nitric acid (1.05–1.10 sp. gr.) for a short time, washing the acid out with hot water, and then boiling with a 25 per cent. solution of sodium hydroxide. This is also washed out with hot water. Reboiling with the above reagents as before diminishes the liability of leaving any soluble portions. As thus prepared the filtering material may be kept indefinitely under water in a wide-mouthed bottle ready for use.

The objections of some chemists[1] to the employment of asbestos, on the ground that it loses weight on using, does not seem to hold when it is prepared as above. A sample boiled as stated with acid and alkali three times lost only two-tenths milligram when two "blanks" of hot dilute Fehling solution, as used in the process above described, were passed through the mineral in a porcelain Gooch crucible.

For use, a layer of asbestos, about 1 cm. in thickness, is placed in a porcelain Gooch crucible to retain the finely divided precipitate, which is filtered by means of suction in the usual manner. The crucible containing the cuprous oxide is then dropped into a triangular frame made of platinum wire, suspended within an iron radiator, or shell, heated to redness. This quickly and thoroughly dries the asbestos without cracking the crucible. After about five minutes the crucible is transferred by means of a pair of nippers to a red-hot platinum crucible, and heated for about fifteen minutes. It is then quickly transferred to a desiccator near at hand to prevent cracking, allowed to cool, and weighed. As cupric oxide is somewhat hygroscopic, it is advantageous to weigh quickly and to keep the balance case as dry as possible. Prolonged heating in the iron radiator would have changed the cuprous oxide to the cupric state. The advantage of transferring the porcelain crucible to a red-hot platinum crucible is that the oxidation is quickly completed, as a much higher temperature is available.

If pressed for time, another determination can be made in the same crucible without cleaning it. As a rule, it is, however, advisable

[1] Killing: Ztschr. angew. Chem., 431 (1894); Praeger: Ztschr. angew. Chem., 520 (1894).

to wash out the cupric oxide by means of hot nitric acid (1.05–1.10 sp. gr.) and then with hot water. The crucible is then heated, cooled, and weighed as before. It must necessarily be weighed, because this treatment with hot nitric acid dissolves some of the asbestos.

If preferred, a Soxhlet's tube may be used to retain the precipitated cuprous oxide. As a porcelain Gooch crucible possessed obvious advantages over this apparatus, I have used it in all my determinations with success.

The cupric reducing powers of dextrose, maltose, and lactose were determined by the method given above. A table for invert sugar was not constructed, because most invert sugar determinations are made by double polarization in a saccharimeter.

Dextrose.

The "cupric reducing power" of dextrose was first determined. This is defined as "the amount of cupric oxide which 100 parts reduce."[1] This may be represented by $\frac{100\ W}{D}$, in which W is the weight of cupric oxide obtained by the given weight of any sugar, and D the weight of cupric oxide formed by an equal weight of dextrose.[2] Hence, if the amount of cupric oxide formed by 1 gram of dextrose be known, the amount of cupric oxide reduced by 1 gram of any other substance, calculated upon this number as a percentage, will represent the cupric oxide reducing power of the substance, which we denote by the symbol K.

The amount of cupric oxide has been determined by O'Sullivan[3] to be 2.205 grams per gram dextrose. The factor for dextrose in terms of cupric oxide is, therefore, the reciprocal of 2.205 or 0.4535. This value, 0.4535, was assumed to be a constant for all amounts of dextrose when used with Fehling's solution in the manner indicated. As such, it was a very convenient quantity, it being only necessary to obtain the weight of cupric oxide formed by the action of a dextrose solution, multiply this by 0.4535, and the amount of dextrose corresponding was obtained. No tables are needed if this assumption be true. Consequently, the determination of dextrose was indeed a very simple one.

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[1] J. Chem. Soc., **2**, 130 (1876).

[2] J. Chem. Soc., Trans., 606 (1879).

[3] Loc. cit.

On an extended investigation of this subject, using various amounts of dextrose on the same volume of Fehling liquor in each determination, I find that the value of 2.205, above given as representing the quantity of cupric oxide obtained by the action of 1 gram of dextrose, is not, as was heretofore assumed, a constant for all weights of dextrose taken, the amount varying from 2.27 grams cupric oxide per gram dextrose for small quantities of sugar to 2.22 grams cupric oxide for the largest amount of dextrose permissible. Allihn,[1] boiling his sugar solutions with the Fehling liquor and reducing the cuprous oxide to copper, obtained analogous varying results.

The purity of the dextrose used was first determined, dextrose anhydride being employed. 10.008 grams of anhydrous dextrose were dissolved in distilled water, and the solution boiled to prevent birotation. It was then transferred to a flask, the capacity of which at 15.5° C. was 100.08 cc., thus giving a solution which contained 0.100 gram dextrose anhydride per cubic centimeter.

The specific gravity of the above solution at 15.5° was determined in the usual manner by means of a picnometer, with thermometer attached.

Capacity picnometer (at 15.5°) = 55.2055 cc.
Dextrose solution (at 15.5°) = 57.3083 grams.

On calculating from these values, we find the specific gravity of a dextrose solution containing 10 grams dextrose in 100 cc. to be 1.03809 at 15.5°.

The specific rotatory power was determined by the usual method, a Schmidt and Haensch saccharimeter being used in polarizing the dextrose solution. The polarizations were carried out in a 200 mm. tube at 20°. To change from the readings of a saccharimeter to the rotary degrees, it is necessary to multiply the reading observed by 0.344, as shown by Rimbach.[2] I have verified this value with concordant results, a Laurent polariscope being used for comparison. The rotation of the above solution was 30.7 divisions. This gives by means of the usual formula $-[\alpha]_D^{20} = \frac{av}{lw}$ — a specific rotatory power of 52.8°, which is in accordance with that obtained by other observers.[3] The dextrose used was consequently pure.

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[1] J. prakt. Chem. (2), **22**, 63.

[2] Ber. d. chem. Ges., **27**, 2282.

[3] Pribram: Monat. f. Chem., **9**, 399; Landolt: Ber. d. chem. Ges., **21**, 191.

For the determination with Fehling liquor, 25 cc. of the dextrose solution at 15.5° were accurately measured from a calibrated burette and made up to 500 cc. with distilled water at the same temperature. This consequently gave a solution each cubic centimeter of which contained 5 mg. dextrose. Various quantities of this were then taken to ascertain the cupric reducing power of dextrose. The results in detail are given below. In each case the combined volumes of the Fehling liquor and the sugar solution were made up to 105 cc., as described above.

Milligrams dextrose.	Cupric oxide obtained.	Cupric oxide per gram dextrose.	Dextrose equivalent.	Mean dextrose equivalent.
12½	0.0283	2.264	0.4416	0.4401
12½	0.0285	2.280	0.4386	
25	0.0569	2.276	0.4393	0.4419
25	0.0565	2.260	0.4425	
50	0.1129	2.258	0.4429	0 4440
50	0.1123	2.246	0.4452	
62½	0.1407	2.251	0.4443	0.4449
62½	0.1403	2.245	0.4454	
75	0.1683	2.244	0.4457	0.4462
75	0.1679	2.239	0.4467	
100	0.2233	2.233	0.4478	0.4483
100	0.2227	2.227	0.4489	
125	0.2776	2.221	0.4503	0.4503
125	0.2782	2.225	0.4493	
125	0.2770	2.216	0.4512	
125	0.2774	2.219	0.4506	
125	0.2777	2.222	0.4500	
140	0.3105	2.218	0.4508	0.4511
140	0.3100	2.215	0.4515	

The foregoing values of the amounts of cupric oxide per gram dextrose are given graphically in curve *A*, Figure 1, and the dextrose equivalents of this in *A*, Figure 2.

From this we get the amount of dextrose corresponding to a given weight of copper oxide by means of the formula:

$$D = (0\,4400 + 0.000037\ W)\ W,$$

in which D is the amount of dextrose, and W the weight of cupric oxide.

The dextrose table given in this article is based on this formula, the values of W varying from 30 to 320.

Maltose.

The cupric reducing power of dextrose is given as 100. Using this as a basis, the reducing force of maltose, as given by O'Sullivan,[1] is 65. Brown and Heron[2] place the value somewhat lower, claiming that 61 is more exact. The results which I have obtained agree very well with this latter number.

In the case of maltose, as with dextrose, it was found that the amount of cupric oxide obtained per gram of sugar was not a constant. The cupric reducing power of various amounts of maltose was, however, found to be almost exactly a constant when referred to the cupric oxide from equal weights of dextrose. That is, calling the reducing power of dextrose 100 for different aliquot parts of that sugar, the cupric reducing power of maltose referred to this standard was always 61.

The specific gravity of maltose was determined in the usual manner. 9.7558 grams maltose anhydride were dissolved in distilled water to 100.08 cc. at 15.5°.

Maltose solution at 15.5° = 57.3049 grams.

On calculating this we find the specific gravity of the above solution to be 1.03803. For a solution containing 10 grams maltose anhydride in 100 cc. it would consequently be 1.03900 at 15.5°.

The specific rotatory power was determined as usual. The rotation of the above solution at 20° in a 200 mm. tube was 77.4 divisions on the saccharimeter scale. This gives $[a]_D^{20} = 136.6°$.

As maltose anhydride is somewhat difficult to prepare, the solutions used to determine the cupric reducing powers were made up to approximately 10 per cent. from the maltose hydrate. The specific gravity of the solutions was then determined. Subtracting from this value 1.00000 — the specific gravity of water — and dividing the remainder by 0.00390, we get the amount of maltose anhydride in 100 cc. of solution.

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[1] Loc. cit.

[2] J. Chem. Soc., Trans., 619 (1879).

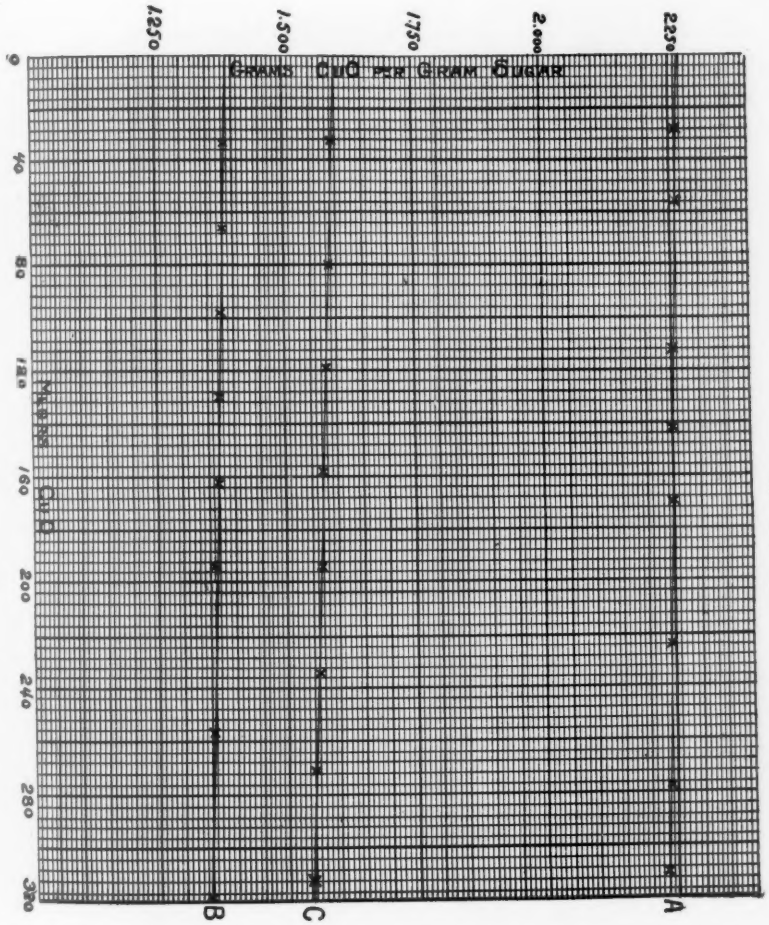

FIG. 1. GRAMS OF CUPRIC OXIDE PER GRAM OF SUGAR AT VARIOUS DEGREES OF DILUTION. *A*, DEXTROSE. *B*, MALTOSE. *C*, LACTOSE.

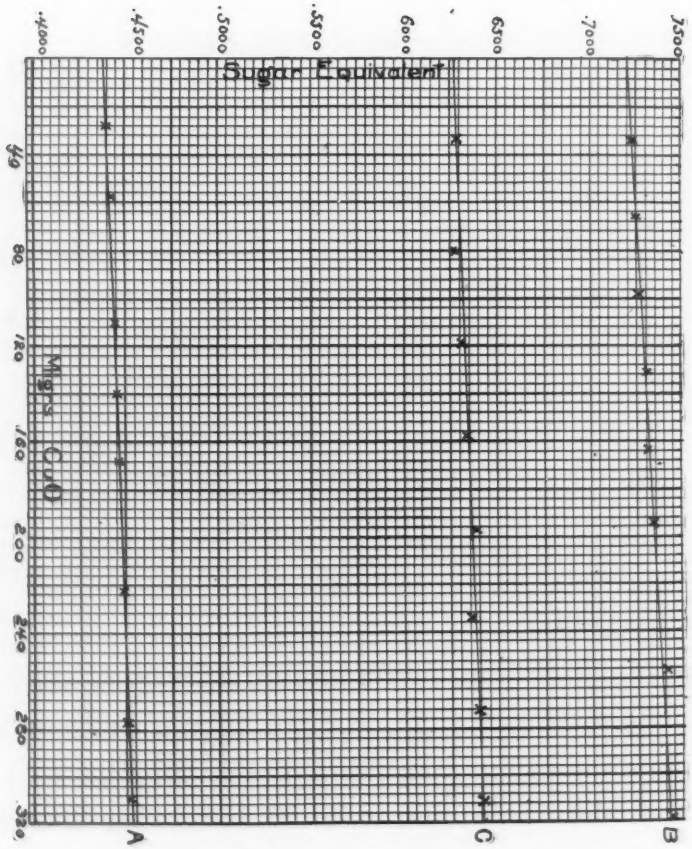

FIG. 2. SUGAR EQUIVALENT CORRESPONDING TO AMOUNT OF CUPRIC OXIDE OBTAINED. *A*, DEXTROSE. *B*, MALTOSE. *C*, LACTOSE.

Maltose solution at 15.5° = 57.2511 grams,

which gives a specific gravity of 1.037054, or 9.501 grams maltose anhydride in 100 cc.

The solution for Fehling determinations was made in the same manner as the dextrose solutions above. Each cubic centimeter of the diluted maltose solution therefore contained 4.75 mg. maltose anhydride.

Milligrams maltose.	Cupric oxide obtained.	Cupric oxide per gram maltose.	Maltose equivalent.	Mean maltose equivalent.
23.75	0.0329	1.386	0.7218	0.7240
23.75	0.0327	1.377	0.7263	
47.5	0.0656	1.381	0.7243	0.7253
47.5	0.0654	1.377	0.7263	
71.25	0.0983	1.380	0.7247	0.7263
71.25	0.0979	1.374	0.7278	
95.0	0.1304	1.373	0.7286	0.7297
95.0	0.1300	1.369	0.7308	
118.75	0.1623	1.370	0.7302	0.7319
118.75	0.1619	1.367	0.7336	
142.5	0.1940	1.361	0.7345	0.7354
142.5	0.1934	1.357	0.7369	
190.0	0.2572	1.353	0.7284	0.7395
190.0	0.2566	1.350	0.7406	
237.5	0.3198	1.347	0.7429	0.7433
237.5	0.3193	1.345	0.7437	

The maltose equivalent in terms of copper oxide is shown in *B*, Figure 2. From this we get the amount of maltose corresponding to a given weight of cupric oxide by the formula:

$$M = (0.7215 + 0.000061\ W)\ W,$$

in which M is the weight of maltose, and W the amount of cupric oxide obtained. It will be seen that these values make the cupric reducing power of maltose 0.61 that of dextrose.

Lactose.

Lactose was investigated in the same manner as the preceding. 10.008 grams lactose anhydride were dissolved in distilled water, boiled, and made up to 100.08 cc. at 15.5°.

The above solution, polarized in a 200 mm. tube at 20°, gave a rotation of 30.7 divisions. This gives the specific rotatory power of lactose of 52.8°.

The amounts of cupric oxide found by the reduction of known weights of lactose were determined as in the previous cases, with the following results:

Milligrams lactose.	Cupric oxide obtained.	Cupric oxide per gram lactose.	Lactose equivalents.	Mean lactose equivalents.
20	0.0319	1.595	0.6269	0.6289
20	0.0317	1.585	0.6308	
50	0.0798	1.596	0.6266	0.6274
50	0.0796	1.592	0.6282	
75	0.1188	1.584	0.6313	0.6323
75	0.1184	1.579	0.6334	
100	0.1577	1.577	0.6340	0.6355
100	0.1570	1.570	0.6369	
125	0.1955	1.564	0.6395	0.6379
125	0.1964	1.561	0.6363	
150	0.2345	1.563	0.6397	0.6404
150	0.2340	1.560	0.6410	
175	0.2729	1.560	0.6412	0.6418
175	0.2724	1.557	0.6424	
200	0.3112	1.556	0.6425	0.6430
200	0.3107	1.553	0.6436	

The cupric oxide values per gram lactose are presented graphically in curve *C*, Figure 1, while the reciprocals of these quantities are shown in *C*, Figure 2. For this latter the amount of lactose corresponding to the weight of cupric oxide obtained is determined by the following:

$$L = (0.6270 + 0.000053\ W)\ W,$$

in which L is the lactose, and W the amount of copper oxide. The accompanying table for lactose is constructed on this basis.

* * * * * * *

It will be seen from the above results that the amount of cupric oxide produced by the action of 1 gram of reducing carbohydrate on Fehling liquor, in the manner described, is not a constant for all dilutions.

The cupric reducing power of maltose is 0.61 that of dextrose.

The following tables for the determination of the reducing sugars in terms of cupric oxide are based on the analytical results presented above, and can be used in the process outlined in the same manner as any other table for the same purpose:

Parts copper oxide.	Parts dextrose.	Parts maltose.	Parts lactose.	Parts copper oxide.	Parts dextrose.	Parts maltose.	Parts lactose.
30	13.2	21.7	18.8	89	39.4	64.7	56.2
31	13.7	22.4	19.5	90	39.9	65.5	56.8
32	14.1	23.1	20.1	91	40.3	66.2	57.4
33	14.6	23.9	20.7	92	40.8	66.9	58.1
34	15.0	24.6	21.4	93	41.2	67.7	58.7
35	15.4	25.3	22.0	94	41.7	68.4	59.3
36	15.9	26.1	22.6	95	42.1	69.1	60.0
37	16.3	26.8	23.3	96	42.5	69.9	60.6
38	16.8	27.5	23.9	97	43.0	70.6	61.2
39	17.2	28.3	24.5	98	43.4	71.3	61.9
40	17.6	29.0	25.2	99	43.9	72.1	62.5
41	18.1	29.7	25.8	100	44.4	72.8	63.2
42	18.5	30.5	26.4	101	44.8	73.5	63.8
43	19.0	31.2	27.1	102	45.3	74.3	64.4
44	19.4	31.9	27.7	103	45.7	75.0	65.1
45	19.9	32.7	28.3	104	46.2	75.7	65.7
46	20.3	33.4	29.0	105	46.6	76.5	66.3
47	20.7	34.1	29.6	106	47.0	77.2	67.0
48	21.2	34.8	30.2	107	47.5	77.9	67.6
49	21.6	35.5	30.8	108	48.0	78.7	68.2
50	22.1	36.2	31.5	109	48.4	79.4	68.9
51	22.5	37.0	32.1	110	48.9	80.1	69.5
52	23.0	37.7	32.7	111	49.3	80.9	70.1
53	23.4	38.4	33.3	112	49.8	81.6	70.8
54	23.8	39.2	34.0	113	50.2	82.3	71.4
55	24.2	39.9	34.6	114	50.7	83.1	72.0
56	24.7	40.5	35.2	115	51.1	83.8	72.7
57	25.1	41.3	35.9	116	51.6	84.5	73.3
58	25.5	42.1	36.5	117	52.0	85.2	74.0
59	26.0	42.8	37.1	118	52.4	85.9	74.6
60	26.4	43.5	37.8	119	52.9	86.6	75.2
61	26.9	44.3	38.4	120	53.3	87.4	75.9
62	27.3	45.0	39.0	121	53.8	88.1	76.6
63	27.8	45.7	39.7	122	54.2	88.9	77.2
64	28.2	46.5	40.3	123	54.7	89.6	77.9
65	28.7	47.2	40.9	124	55.1	90.3	78.5
66	29.1	47.9	41.6	125	55.6	91.1	79.1
67	29.5	48.6	42 2	126	56.0	91.8	79.8
68	30.0	49.4	42.8	127	56.5	92.5	80.4
69	30.4	50.1	43.5	128	56.9	93.3	81.1
70	30.9	50.8	44.1	129	57.3	94.0	81.7
71	31.3	51.6	44.7	130	57.8	94.8	82.4
72	31.8	52.3	45.4	131	58.2	95.5	83.0
73	32.2	53.0	46.0	132	58.7	96.2	83.6
74	32.6	53.8	46.6	133	59.1	97.0	84.2
75	33.1	54.5	47 3	134	59.6	97.7	84.9
76	33.5	55.2	47.9	135	60.0	98.4	85.5
77	34.0	56.0	48.5	136	60.5	99.2	86.1
78	34.4	56.7	49.2	137	60.9	99.9	86.8
79	34.9	57.4	49.8	138	61.3	100.7	87.4
80	35.4	58.1	50.5	139	61.8	101.4	88.1
81	35.9	58.9	51.1	140	62.2	102.1	88.7
82	36 3	59.6	51.7	141	62.7	102.8	89.3
83	36.8	60.3	52.4	142	63.1	103.5	90.0
84	37.2	61.1	53.0	143	63.6	104.3	90.6
85	37.7	61.8	53.6	144	64.0	105.0	91.3
86	38.1	62.5	54.3	145	64.5	105.8	91.9
87	38.5	63.3	54.9	146	64.9	106.5	92.6
88	39.0	64.0	55.5	147	65.4	107.2	93.2

Parts copper oxide.	Parts dextrose.	Parts maltose.	Parts lactose.	Parts copper oxide.	Parts dextrose.	Parts maltose.	Parts lactose.
148	65.8	108.0	93.9	207	92.6	151.8	132.1
149	66.3	108.7	94.5	208	93.1	152.5	132.8
150	66.8	109.5	95.2	209	93.5	153.3	133.4
151	67.3	100.2	95.8	210	94.0	154.1	134.1
152	67.7	111.0	96.5	211	94.4	154.8	134.7
153	68.3	111.7	97.1	212	94.9	155.6	135.4
154	68.7	112.4	97.8	213	95.3	156.3	136.0
155	69.2	113.2	98.4	214	95.8	157.1	136.7
156	69.6	113.9	99.1	215	96.3	157.8	137.3
157	70.0	114.7	99.7	216	96.7	158.6	138.0
158	70.5	115.4	100.4	217	97.2	159.3	138.6
159	70.9	116.1	101.0	218	97.6	160.0	139.3
160	71.3	116.9	101.7	219	98.1	160.8	139.9
161	71.8	117.6	102.3	220	98.6	161.5	140.6
162	72.3	118.4	103.0	221	99.0	162.3	141.2
163	72.7	119.1	103.6	222	99.5	163.0	141.9
164	73.2	119.9	104.3	223	99.9	163.7	142.5
165	73.6	120.6	104.9	224	100.4	164.5	143.2
166	74.1	121.4	105.6	225	100.9	165.3	143.8
167	74.5	122.1	106.2	226	101.3	166.0	144.5
168	74.9	122.9	106.9	227	101.8	166.8	145.1
169	75.4	123.6	107.5	228	102.2	167.5	145.8
170	75.8	124.4	108.2	229	102.7	168.3	146.4
171	76.3	125.1	108.8	230	103.1	169.1	147.0
172	76.8	125.8	109.5	231	103.6	169.8	147.7
173	77.3	126.6	110.1	232	104.0	170.6	148.3
174	77.7	127.3	110.8	233	104.5	171.3	149.0
175	78.2	128.1	111.4	234	105.0	172.1	149.6
176	78.6	128 8	112.0	235	105.4	172.8	150.3
177	79.1	129.5	112.6	236	105.9	173.6	150.9
178	79.5	130.3	113 3	237	106.3	174.3	151.6
179	80.0	131.0	113.9	238	106.8	175.1	152.2
180	80.4	131.8	114 6	239	107.2	175.8	152.9
181	80.8	132.5	115.2	240	107.7	176.6	153.5
182	81.3	133.2	115.8	241	108.1	177.3	154.2
183	81.8	134.0	116.5	242	108.6	178.1	154.8
184	82.2	134.7	117.1	243	109.0	178.8	155.5
185	82.7	135.5	117.8	244	109.5	179.6	156.1
186	83.1	136.2	118.4	245	109.9	180.3	156.8
187	83 5	136.9	119.1	246	110.4	181.1	157.4
188	84.0	137.7	119.7	247	110.9	181.8	158.1
189	84.4	138.4	120.4	248	111.3	182.6	158.7
190	84.9	139.1	121.0	249	111.8	183.3	159.4
191	85.4	139.9	121.7	250	112.3	184.1	160.0
192	85.9	140.6	122.3	251	112.7	184.8	160.7
193	86.3	141.4	123.0	252	113 2	185.5	161.3
194	86 8	142.1	123.6	253	113.7	186.3	162.0
195	87.2	142.8	124.3	254	114.1	187.1	162.6
196	87.7	143.6	124.9	255	114.6	187.8	163.3
197	88.1	144.3	125.6	256	115.0	188.6	163.9
198	88.6	145.1	126.2	257	115.5	189.3	164.6
199	89.0	145.8	126.9	258	116 0	190.1	165.2
200	89.5	146.6	127.5	259	116.4	190.8	165.9
201	89.9	147.3	128.2	260	116.9	191.6	166.5
202	90.4	148.1	128.8	261	117.3	192.4	167.2
203	90.8	148.8	129.5	262	117.8	193.1	167.8
204	91.3	149.6	130.1	263	118.3	193.9	168.1
205	91.7	150.3	130.8	264	118.7	194.6	169.5
206	92.2	151.1	131.5	265	119.2	195.4	169.8

Parts copper oxide.	Parts dextrose.	Parts maltose.	Parts lactose.	Parts copper oxide.	Parts dextrose.	Parts maltose.	Parts lactose.
266	119.6	196.1	170.4	294	132.5	217.4	188.9
267	120.1	196.9	171.1	295	133.0	218.2	189.5
268	120.6	197.7	171.7	296	133.4	218.9	190.2
269	121.0	198.4	172.4	297	133.9	219.7	190.8
270	121.4	199.2	173.0	298	134.3	220.4	191.5
271	121.9	199.9	173.7	299	134.8	221.2	192.1
272	122.4	200.7	174.4	300	135.3	221.9	192.8
273	122.8	201.5	175.0	301	135.7	222.7	193.4
274	123.3	202.2	175.7	302	136.2	223.5	194.1
275	123.7	203.0	176 3	303	136 6	224.2	194.7
276	124.2	203.7	177.0	304	137.1	225.0	195.3
277	124.6	204.5	177.6	305	137.6	225.8	196.0
278	125.1	205.2	178.3	306	138.0	226.5	196.6
279	125.6	206.0	178.9	307	138.5	227.3	197.3
280	126.1	206.8	179.6	308	138.9	228.1	197.9
281	126.5	207.5	180.2	309	139.4	228.8	198.6
282	127.0	208.3	180.9	310	139.9	229.6	199.3
283	127.4	209.0	181.5	311	140.3	230.4	199.9
284	127.9	209.8	182.2	312	140.8	231.1	200.6
285	128.3	210.5	182.9	313	141.2	231.9	201.3
286	128.8	211.3	183.6	314	141.7	232.7	202.0
287	129.3	212.1	184.2	315	142.2	233.4	202.6
288	129.7	212.8	184.9	316	142.6	234.2	203.3
289	130.2	213.6	185.6	317	143.1	234.9	203.9
290	130.6	214.3	186.2	318	143.6	235.7	204.6
291	131.1	215.1	186.9	319	144.0	236.5	205.3
292	131.5	215.9	187.6	320	144.5	237.2	205.9
293	132.0	216.6	188.2				

Supplementary Table for Glucose Analysis.

The amounts of cupric oxide given above are those obtained by the use of absolute weights of sugar. The tables are constructed on this basis. In the case of a mixed product, like commercial glucose, which may be considered made up of the simple bodies dextrin, maltose, and dextrose, it is far more convenient to determine the total carbohydrates present in solution by means of the specific gravity than by drying the glucose, and obtaining in this way the total solids. For this purpose an arbitrary value is taken which shall represent the influence of 1 gram of a mixture of the three substances above mentioned, on the specific gravity if dissolved to 100 cc. in distilled water. Brown and Heron[1] claim that this influence on the specific gravity of 1 gram starch conversion product in 100 cc. is 0.00386. This value has been determined to be correct for solutions of cane sugar, and is much used for glucose work

[1] Loc. cit.

As above mentioned, the specific gravity of a dextrose solution containing 10 grams dextrose anhydride in 100 cc. is 1.03809 at 15.5°. To determine the cupric reducing power of a substance, using the value 3.86 as a divisor, it therefore becomes necessary to change the figures given in the tables to conform to this new factor; that is, the dextrose equivalents must be multiplied by $\frac{386}{381}$, which has been done for convenience of reference in the following table:

Copper oxide obtained.	Dextrose equivalent.	Copper oxide obtained.	Dextrose equivalent.	Copper oxide obtained.	Dextrose equivalent.
5	0.4461	115	0.4502	225	0.4543
10	0.4463	120	0.4504	230	0.4545
15	0.4465	125	0.4506	235	0.4547
20	0.4467	130	0.4508	240	0.4549
25	0.4468	135	0.4510	245	0.4551
30	0.4470	140	0.4512	250	0.4553
35	0.4472	145	0.4513	255	0.4555
40	0.4474	150	0.4515	260	0.4557
45	0.4476	155	0.4517	265	0.4558
50	0.4478	160	0.4519	270	0.4560
55	0.4480	165	0.4521	275	0.4562
60	0.4482	170	0.4523	280	0.4564
65	0.4484	175	0.4525	285	0.4566
70	0.4485	180	0.4527	290	0.4568
75	0.4487	185	0.4528	295	0.4570
80	0.4489	190	0.4530	300	0.4572
85	0.4491	195	0.4532	305	0.4574
90	0.4493	200	0.4534	310	0.4576
95	0.4495	205	0.4536	315	0.4578
100	0.4497	210	0.4538	320	0.4580
105	0.4498	215	0.4540		
110	0.4500	220	0.4542		

Thus a solution containing 100 mg. of mixed carbohydrates, using the factor 0.00386, if it formed 200 mg. cupric oxide by reduction of the Fehling solution in the manner above described, would have a cupric reducing power, or K_{386}, of 90.68.

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MICRO-ORGANISMS AND STERILIZING PROCESSES IN THE CANNING INDUSTRY.

By SAMUEL C. PRESCOTT and W. LYMAN UNDERWOOD.

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The process of hermetically sealing food materials in jars or cans and their subsequent sterilization by heat has become an enormous and most important industry. From a sanitary point of view, canned foods are of the highest value, because if properly prepared they are free from all bacteria. The enormous use of these goods testifies to the high regard with which they are held, and sanitarians cannot fail to view this fact with satisfaction.

The magnitude of the canning industry at present may be indicated by figures showing the number of cans packed annually, in the United States alone, of some of the larger branches.

Sardines,	80,000,000 cans.	Corn,	72,000,000 cans.
Salmon,	96,000,000 cans.	Tomatoes,	120,000,000 cans.

Oysters (in Baltimore alone), 1,250,000 bushels.

Besides these are packed very extensively, lobsters, clams, meats, soups, peas, beans, and fruits.

It occasionally happens that deterioration and loss of some food materials so prepared may result if the sterilization, or as it is known to the trade, "processing," is not conducted in a thorough and scientific manner. This trouble is not confined to any one class of foods, but may be encountered in vegetables, meats, fish, oysters, clams, and lobsters, although it is a notable fact that spiced goods usually keep indefinitely.

At the suggestion and under the supervision of Professor Sedgwick we have made a careful experimental study of one branch of the industry, viz., the packing of clams and lobsters.

It is generally believed that the canning industry was originated by Nicholas Appert,[1] a Frenchman, who in 1810 preserved fruit by

[1] Appert: Art of Preserving Animal and Vegetable Substance. (London, 1812.) Bigelow: Elements of Technology, p. 499. (1831.) Edinburgh Review, **23**, p. 104.

heating and hermetically sealing in glass jars. Probably the first to adopt these methods in America was William Underwood, an Englishman, who in 1821 began in Boston to preserve foods according to Appert's methods. These methods of Appert were followed until about 1840, when glass jars were largely displaced by tin cans. This substitution, it is believed, originated a year or two before with Charles Mitchell, a Scotchman, who packed corn and lobsters in tin cans near Eastport, Maine.

The advent of tin cans caused the first great stride in the business, as it opened a large field for work in the preservation of meat, vegetables, and fish. Salmon was probably first packed at St. Johns, N. B., in 1839, and shipped directly to the Pacific coast, while at present salmon packing is confined to the Pacific States. About the same time oysters shipped in barrels from Baltimore were packed in Boston. Everything in connection with the process was kept as secret as possible, therefore only a few firms were enabled to engage in the business, but gradually through employees the process became more public. During the war the trade was given a tremendous impetus through the government's requiring canned food supplies for the army, and since the war the growth of the industry has been constant and steady.

With the increased demand for canned goods came also the necessity for better methods. The old method of procedure in packing fish was as follows: After packing and sealing, the cans were heated for an hour in boiling water, then taken out and "tapped" or vented in order to expel air and produce a vacuum, sealed again and boiled for an hour and a half, again tapped and sealed and given a final boiling of three hours. Thus the total time of heating was five and one-half hours, and in many cases even more time was given.

It was formerly believed that the vacuum was the principal factor in keeping the goods, a belief still clung to by many packers. The vacuum, although unnecessary for sterilization, is necessary for inspection. Before the cans are put on the market each one is thoroughly examined to detect any unsoundness, or what is known to the trade as "swells." This examination consists of inspection and sounding the cans after "processing," *i. e.*, sterilization. Sound cans should show a vacuum, as indicated by concavity of the ends, and should emit a peculiar note when struck. On the other hand, unsound cans which have not yet swelled give a characteristic dull tone when struck. By the difference in the quality of the tones a skilled inspector can

instantly distinguish between sound and unsound cans. Any cans not showing a vacuum are rejected, the annual loss resulting from this source being very large. After inspection the cans are generally put in stacks, and before leaving the packer are again examined. It sometimes happens, however, that spoiling without swelling occurs. For the detection of such cases, special methods must be employed. Such cases are sometimes found in canned clams, and more frequently in lobster, in the latter case being known to the trade as "black lobster."

Since long continued heating tends to disintegrate and darken the foods which it is desired to preserve as fresh as possible, it has always been the aim of packers to reduce the bath time as much as possible. Consequently there has been a gradual shortening of the time of heating in the water bath, until at present the average treatment by this method is from two and one-half to three hours, divided into two periods.

In 1863 a "chemical bath," consisting of calcium chloride, was introduced to some extent. Owing to the large amount of the salt in solution and its consequent high boiling point, a temperature of 250° F. could be easily obtained. With this temperature the time of heating could be greatly lessened, and at the same time sterilization was assured. In one form of this process a lozenge of sodium sulphite was fastened on the under side of the cover of each can by means of fusible metal. The object of this was "to decompose the air remaining in the can." This method of procedure was found to be impracticable, owing to the frequent explosions of the cans. This bath was in use but a short time, being followed by a return to the earlier methods.

The introduction of digesters or "retorts," about 1870, was the next and most recent step in the development of sterilizing apparatus. By their use an actual temperature of 250° F. (127° C.) may be easily obtained both inside and outside the can; so explosions are avoided. The corresponding pressure is fourteen pounds. The only precaution required is to reduce the temperature and pressure cautiously. They have not been accepted as entirely satisfactory, however, on account of the darkening of the goods caused by long continued heating. It is probable that retorts are now used less than formerly in some quarters, through ignorance of their effectiveness, yet it is well known that many packers are using them with excellent results.

Examination of "Swelled" Cans, and Descriptions of the Bacteria Found.

As has been stated above, all cans before they are put upon the market are carefully tested for imperfections, and any showing leakage or swelling are rejected, and the annual loss from these sources is very heavy. Our investigations began with a careful examination of a large number of cans of spoiled clams and lobsters. The contents of such cans were found to be badly decomposed, in some cases almost entirely liquefied, much darkened in color, and of a very disagreeable odor. Bacterial examination showed that in every case where spoiling had occurred, living bacteria were present in great numbers. In sound cans, on the other hand, no living bacteria could be detected, and the contents proved to be sterile. As would be supposed in the present state of bacteriology, there is no reason to doubt that swelling and decomposition are invariably the result of bacterial action. In some cases a can contained a culture apparently pure, while other cans might contain a mixture of several species.

The ordinary bacteriological methods, with some modifications, served for the separation of these organisms into distinct species, and made possible their cultivation in pure cultures in artificial media. Of the nine species of bacteria obtained, two are micrococci, while the other seven are classed among the bacilli. All of them are noticeably rapid in their development in an incubator at blood heat (98° F., 37½° C.) both in liquid and on solid media, while they grow slowly at a temperature of 70° F. (20° C.). They may be readily stained by the usual staining reagents. In several of the forms endospore formation has been observed, and these forms are likewise noticeable for the rapidity with which such sporulation occurs. The following detailed descriptions will show some of the characteristics of these species:

FIG. 1. BACILLUS NO. 1.
×650.

FIG. 2. BACILLUS NO. 1, SPORES.
×650.

BACILLUS NO. 1. (Figures 1 and 2.)

GENERAL CHARACTERS.	*Shape and arrangement:* Long rods with rounded ends occurring singly, and in chains of varying lengths. Often shows a gelatinous sheath when grown in liquid culture. *Size:* 4–7 μ x 1.5 μ. *Motility:* Moves with serpentine motion. *Spore formation:* Large oval centrally located spores. Develop with ease. *Relation to temperature:* Grows at both 20° and 37½°, but better at the latter temperature. *Relation to air:* Aërobe and facultative anaërobe. *Relation to gelatin:* Liquefies readily. *Color:* Creamy white.
GELATIN.	*Stick culture:* Growth extends throughout line of puncture. The gelatin is liquefied, forming a broad trumpet-shaped liquid portion, at the bottom of which is a small amount of flocculent precipitate. Film formed on surface, which breaks up and settles, leaving a layer of clear liquid at top. Entirely liquid after three weeks. *Plate culture:* Surface colonies: First appear as small white dots. Liquefaction sets in at once, first appearing as a clear ring of liquid gelatin surrounding the colony. Under low power there is seen a dark granular center, and an outer ring of paler threads interwoven and forming a thin, irregularly circular zone. Flocculent ppt. at bottom of the saucer-shaped depression caused by each colony.
AGAR.	*Streak culture:* A moist, creamy white, smooth, shiny growth covering nearly the whole surface of the agar. Edges appear granular or "frosty." *Plate culture:* Surface colonies: First develop as circular shiny colonies with sharp outline. An irregular film is soon formed which extends out on all sides, giving an irregular, somewhat branched appearance; dot at center, and faint concentric rings. Submerged colonies small, oval or spherical.
POTATO.	A gray slimy growth, extending over large part of the surface. This later becomes cheesy and rough on surface. Potato darkened.
MILK.	Is coagulated, and later the coagulum is dissolved. Acidity, neutral.
SMITH SOLUTION.	No gas produced. Heavy sediment. Much turbidity, and film on surface. Strongly acid.
NITRATE.	Is reduced to nitrite but slightly.
BOUILLON.	Film on surface. Turbid. Heavy sediment of a flaky nature.

BACILLUS No. 2.

GENERAL CHARACTERS.	*Shape and arrangement:* Short rods, occurring singly and in chains of 3–6 elements. *Size:* 1.5–1.8 μ x .6μ. *Motility:* Motile. *Spore formation:* Not observed. *Relation to temperature:* Develops rapidly at 37½° C., more slowly at 20°. *Relation to air:* Aërobe and facultative anaërobe. *Relation to gelatin:* Does not liquefy. *Color:* Pale yellow.
GELATIN.	*Stick culture:* No growth visible until after second day. On fifth day hazy growth is shown all along the line of inoculation. Mass of small rounded colonies on surface. *Plate culture:* Surface colonies: First appear as circular shining droplets almost transparent. After two weeks colonies are ½″ in diameter, elevated, rough, with a dot at center, and irregularly concentric rings. Edge of colony crenated or roughly scalloped. Submerged colonies, small, circular and brownish in color.
AGAR.	*Streak culture:* On second day surface is covered with a thin, rough, pale yellow, shiny layer. *Plate culture:* Surface colonies: Circular grayish white colonies somewhat elevated, and sometimes slightly scalloped at edges. Surface rather dull. Dot at center under microscope appears to be shaped like red blood corpuscles, thinner at center than at rim. Sub. colonies: Very small, circular or oval.
POTATO.	Growth for several days almost invisible. Later a scanty, moist, pale yellow growth, following closely the line of inoculation.
MILK.	Is coagulated, forming a solid mass. Strongly acid.
SMITH SOLUTION.	No gas produced. Turbid throughout. Film on surface. Strongly acid. Considerable sediment.
NITRATE.	Is reduced to nitrite with rapidity.
BOUILLON.	Faintly turbid on second day. Solution becomes turbid throughout. Film on surface, and heavy flocculent precipitate.

BACILLUS NO. 3.

General Characters.	*Shape and arrangement:* Stout rods with rounded ends occurring singly and in chains. *Size:* 2–3 μ x 1.75 μ. *Motility:* Motion serpentine and rapid. *Spore formation:* Oval, centrally located spores 1.8 μ x 1.2 μ. *Relation to temperature:* Growth rapid at 37½°; slower at 20°. *Relation to air:* Aërobe and facultative anaërobe. *Relation to gelatin:* Liquefies. *Color:* White.
Gelatin.	*Stick culture:* Development throughout entire length. Liquefies in trumpet shape. Thick film on surface, and heavy flocculent precipitate. *Plate culture:* Surface colonies. Nearly circular with dot at center, concentric rings. Liquefaction commences at once, and a veil-like mass collects at the bottom of the liquefied portion. Under low power the edges of the colonies appear to be made of bacterial filaments which extend from the central mass. Submerged colonies very small and spherical.
Agar.	*Streak culture:* A white, moist, wrinkled growth extending over the whole surface. *Plate culture:* Granular, moist, shiny colonies, dark at center, irregular in outline; edges thick and rough. Tendency to spread.
Potato.	Dirty white, moist layer spreading over the whole surface. Potato much darkened.
Milk.	Is coagulated; coagulum later dissolved.
Smith Solution.	No gas produced. Heavy film on surface and much sediment. Strongly acid.
Nitrate.	Not reduced. Film on surface.
Bouillon.	Growth at surface, then a clear layer below, and at bottom a heavy flocculent precipitate.

BACILLUS NO. 4.

GENERAL CHARACTERS.	*Shape and arrangement:* Rods with rounded ends, occurring singly or in long threads arranged side by side. *Size:* 3–6 μ x 1 μ. *Motility:* Very motile; darting motion. *Spore formation:* Oval centrally located spores 2 μ x 1 μ are readily formed. *Relation to temperature:* Develop rapidly at 37½° C., but slowly at 20°. *Relation to air:* Aërobe and facultative anaërobe. *Relation to gelatin:* Liquefies readily. *Color:* Pale brownish or grayish.
GELATIN.	*Stick culture:* Development quite rapid. Liquefies, giving a liquefied portion having shape of an inverted cone. Film on surface, and flocculent material in suspension. *Plate culture:* Surface colonies: Small circular white liquefying colonies; under low power appear irregularly circular, sharply defined and granular. A ring of liquefied gelatin surrounds each colony almost as soon as the colonies are visible. Submerged colonies very small; spherical.
AGAR.	*Streak culture:* Smooth, white, thin layer of dull luster extending all over surface of the agar. *Plate culture:* Surface colonies: Yellowish white colonies varying in size from small dots to ¼″ in diameter. Nearly circular, dot at center and concentric rings. Submerged colonies: Irregular in shape; very small.
POTATO.	A white pasty, scanty growth at first develops. This later spreads over the whole surface, forming a dry, much wrinkled brown layer.
MILK.	Casein coagulated; coagulum dissolved almost completely. Alkaline.
SMITH SOLUTION.	No gas produced. Slightly turbid, heavy sediment. Growth at surface, neutral reaction.
NITRATE.	Is reduced to nitrite vigorously.
BOUILLON.	Turbid throughout; stringy; tough film on surface, and heavy precipitate in lower third of tube.

BACILLUS NO. 5.

GENERAL CHARACTERS.	*Shape and arrangement:* Bacilli with rounded ends, occurring singly and in chains. *Size:* 3–5 μ long x 1.2–1.5 μ broad. *Motility:* Motion serpentine. *Spore formation:* Not observed. *Relation to temperature:* Rapid development at 37½° C., slow at 20°. *Relation to air:* Aërobe and facultative anaërobe. *Relation to gelatin:* Liquefies rapidly. *Color:* White.
GELATIN.	*Stick culture:* Growth throughout whole line of inoculation. Liquefaction sets in about third day, forming a trumpet-shaped liquefied portion. Film on surface, and flocculent precipitate at lower part of liquefied portion. *Plate culture:* Surface colonies: White circular colonies which begin to liquefy as soon as they are of the size of a pin head, and form depressions or cavities in the gelatin. Under low power they appear to be made up of long interlacing threads which extend from the edge in hair-like processes. Submerged colonies, small, brown, and granular.
AGAR.	*Streak culture:* A pasty thick white growth, rapidly spreading over the whole surface. *Plate culture:* Surface colonies: Thin spreading colonies often coarsely branched; rather large, granular, and dull in luster.
POTATO.	Watery, white growth, later becoming dry and about the same color as the potato, and extending over a large portion of the surface.
MILK.	Is coagulated, and coagulum dissolved. Acidity, neutral.
SMITH SOLUTION.	No gas produced. Turbid throughout. Film on surface. Much sediment. Strongly acid.
NITRATE.	Is reduced to nitrite.
BOUILLON.	Film on surface which breaks up, forming a heavy flaky sediment.

BACILLUS NO. 6.

General Characters.	*Shape and arrangement:* Bacilli, occurring singly and in short chains. *Size:* 1.5– μ x 3.5 μ. *Motility:* Motile. *Spore formation:* Not observed. *Relation to temperature:* Grows readily at 37½° C., less rapidly at 20° C. *Relation to air:* Aërobe and facultative anaërobe. *Relation to gelatin:* Liquefies rapidly. *Color:* Yellow.
Gelatin.	*Stick culture:* Development begins at surface. Liquefaction quickly sets in, and a trumpet-shaped liquefied portion is formed. *Plate culture:* Surface colonies: Yellow, circular, shiny colonies, bluish by transmitted light. Plate is entirely liquefied on fourth or fifth day. The colonies float in the liquefied gelatin, appearing as small yellow spheres.
Agar.	*Streak culture:* A thick, lustrous, moist layer covering the whole surface. Pale orange yellow in color. *Plate culture:* Small dome-shaped surface colonies with sharply defined edges. Yellow. Submerged colonies, very small brownish spheres.
Potato.	Growth at first thin and watery, and pale yellow in color, later becoming orange yellow, and spreads over the whole surface. Potato is darkened.
Milk.	Is coagulated. Yellow at surface. Coagulum is later dissolved. Neutral.
Smith Solution.	No gas produced. Solution turbid throughout. Yellow sediment and yellow growth at surface.
Nitrate.	Not reduced. Turbid.
Bouillon.	Very turbid. Heavy, pale yellow sediment.

FIG. 3. BACILLUS NO. 7.
×650.

FIG. 4. BACILLUS NO. 7, SPORES.
×650.

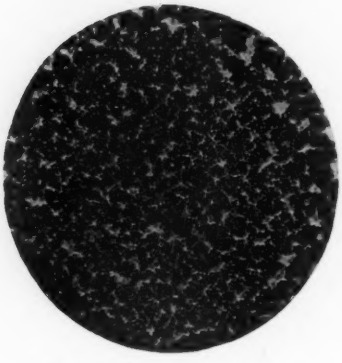

FIG. 5. MICROCOCCUS NO. 1.
×650.

BACILLUS NO. 7. (Figures 3 and 4.)

GENERAL CHARACTERS.	*Shape and arrangement:* Long slender bacilli with rounded ends, generally occurring singly. *Size:* 3–10 μ x 1.5 μ. *Motility:* Motile. *Spore formation:* Forms drumstick-shaped spores. *Relation to temperature:* Develops rapidly at 37½°, slowly at 20°. *Relation to air:* Anaërobe and facultative aërobe. *Relation to gelatin:* Non-liquefying. *Color:* Yellowish white.
GELATIN.	*Stick culture:* Development is very slight, and growth takes place slowly. *Plate culture:* Surface colonies: Small, circular, whitish colonies, regular in outline, and sharply defined. Submerged colonies appear as small spherical dots.
AGAR.	*Streak culture:* Smooth, lustrous layer covering the whole surface of the agar. *Plate culture:* Smooth, circular, rather small white colonies. Outline sharply defined. No characteristic markings. Submerged colonies small, spherical, or oval dots.
POTATO.	Development very slow and slight. Lumpy growth after several days.
MILK.	Not coagulated. Acidity, neutral.
SMITH SOLUTION.	No gas produced. Slightly turbid.
NITRATE.	Not reduced to nitrite.
BOUILLON.	Turbid throughout. Film on surface and sediment.

MICROCOCCUS NO. 1. (Figure 5.)

GENERAL CHARACTERS.	*Shape and arrangement:* Cocci; generally in pairs. *Size:* 1 μ in diameter. *Motility:* Motile; in pairs, sometimes rotation about center. *Spore formation:* Not observed. *Relation to temperature:* Rapid development at 37½°. Slow at 20° *Relation to air:* Aërobe and facultative anaërobe. *Relation to gelatin:* Non-liquefying. *Color:* Yellow.
GELATIN.	*Stick culture:* Growth first appears at surface. Below surface development is very slow. Yellow growth at surface. *Plate culture:* Surface colonies: Circular with sharply defined edges and yellow color. Under microscope show granular appearance and a deep color at center, surrounded by a paler ring. Submerged colonies show no clear markings, but appear as very small spherical dots.
AGAR.	*Streak culture:* Smooth, lustrous yellow layer covering much of the surface. *Plate culture:* Small, shiny, pale yellow circular colonies, dome-shaped, and smooth in appearance. Submerged colonies generally oval and brownish.
POTATO.	Development slight, a moist, lumpy growth appearing after several days.
MILK.	Not coagulated. Acidity, neutral.
SMITH SOLUTION.	No gas produced. Slight turbidity. Alkaline reaction.
NITRATE.	Not reduced to nitrite.
BOUILLON.	Turbid throughout; film on surface. Considerable sediment.

MICROCOCCUS NO. 2.

GENERAL CHARACTERS.	*Shape and arrangement:* Cocci; occurring sometimes singly, often in groups. *Size:* About .9 μ in diameter. *Motility:* Non-motile. *Spore formation:* Not observed. *Relation to temperature:* Develops quickly at 37½° C., more slowly at 20°. *Relation to air:* Aërobe and facultative anaërobe. *Relation to gelatin:* Liquefies slowly. *Color:* Yellow.
GELATIN.	*Stick culture:* Development chiefly at surface. A yellow film is formed and liquefaction takes place, a cup-shaped depression resulting. *Plate culture:* Small, circular or somewhat irregular colonies, which under low power appear granular; yellow at center, shading into white at the clearly marked edges. They appear bluish by transmitted light. Submerged colonies, spherical or oval, and brownish in color.
AGAR.	*Streak culture:* Bright yellow, thick, sticky growth, branching and extending over the whole surface. *Plate culture:* Pale yellow, raised, circular, shiny, smooth colonies, generally very small. Submerged colonies, pale, oval, or spherical.
POTATO.	Thin, branching, spreading growth of citron yellow, covering much of the surface of the potato. Later, becomes dry, ridged, and roughened.
MILK.	Not coagulated. Neutral reaction.
SMITH SOLUTION.	No gas produced. Slight amount of sediment and some turbidity. Alkaline reaction.
NITRATE.	Not reduced to nitrite.
BOUILLON.	Very turbid throughout. Sediment heavy and viscous.

It is not to be inferred that these include all the species of bacteria which occur in swelled cans even of clams and lobsters. Of those which produce the spoiling of fruits and vegetables, we have as yet slight knowledge.[1]

Inoculation Experiments.

If the organisms isolated from decomposing material are the agents by means of which the decomposition is effected, it should be possible to reproduce this spoiling at will by inoculation of sterile material with cultures of the organisms in question, external conditions being the same in both cases. To determine this point experimentally, sterile cans have been seeded with pure cultures of bacteria obtained from spoiled cans.

For these experiments cans were tested by incubation at blood heat until it was demonstrated beyond doubt that no swelling would result. The outside of these cans was then sterilized either by passing through a flame or by washing in mercuric chloride. A small hole was then made in the top of the can with a hot awl, the can either being held directly in the flame of a Bunsen burner or the operation being carried on in a previously sterilized glass chamber. The bacteria were introduced by means of a platinum needle, and the strictest precautions against contamination were observed. As soon as inoculated the cans were sealed with solder, and, after shaking, were replaced in an incubator at a temperature of $37\frac{1}{2}$° C. (98° F.). A number of similar cans were similarly treated in every way, except that no germs were introduced, the object of this treatment being to show that puncturing the can, thus allowing air to enter, will not cause spoiling if the operation is carried on with due precautions. To illustrate these points more fully a few results are here given:

[1] A bacterial study of the spoiling of corn, known to the trade as "sour corn," has already been begun, and a number of experiments are now in progress.

No. of cans.	Treatment.	Incubated.	Results.
7	Punched, but not seeded.	37½° C.	All kept perfectly.
5	Punched, not seeded.	37½	All kept perfectly.
5	Punched, not inoculated.	37½	All kept perfectly.
16	Inoculated.	37½	14 spoiled.
3	Inoculated.	37½	All spoiled.
12	Inoculated.	37½	7 spoiled.
5	Inoculated.	37½	All spoiled.

The results, as shown above, prove that spoiling is due to the action of the living bacteria in the cans. Moreover, the cans in which spoiling was thus brought about showed, when opened, the blackening and liquefaction characteristic of the original spoiled cans, thus proving that the bacteria isolated were the specific causes of spoiling.

An investigation was next made of the efficiency of the ordinary water-bath treatment. Sterile cans were seeded, as above described, with germs derived from spoiled cans. After seeding, however, they were subjected to heat in the water bath exactly as is done on a commercial scale, for a length of time varying from two and one-half to four hours. This time was divided into two periods, the cans being tapped between the two heatings. As will be shown by the following figures, quite a large percentage of the cans treated in this manner spoiled:

No. of cans.	Time of heating. (Hours.)	Incubated.	Results.
7	1 + 1 + 1	37½° C.	All spoiled.
8	1 + 1½	37½	All spoiled.
7	1 + 1 + 1	20	All spoiled.
8	1 + 1½	20	All spoiled.
16	½ + ½ + ½	37½	14 spoiled.
8	1½ + 1½	37½	All spoiled.
3	1½ + 1½	37½	All spoiled.
3	1 + 1½	37½	2 spoiled.
63			58

From these figures it is seen that 92 per cent. of the cans spoiled, a far greater percentage of loss than occurs in practice. This is to be accounted for chiefly by the fact that in these cans have been planted thousands of bacteria of species which have withstood this temperature in the original spoiled cans, while in the ordinary packing the admission of these bacteria is a matter of chance. Moreover, the temperature at which these cans are incubated appears to be specially advantageous for the rapid development of those organisms which have not been killed by the heat, so the test is unusually severe. It should be distinctly understood that these results do not necessarily signify that a large percentage of the cans receiving water-bath treatment on a commercial scale should spoil if allowed to stand at blood heat, but are valuable because of the practical demonstration that this process is insufficient when such bacteria are present, and is unsafe at all times because of the possibility of such infection.

Bacteriological examination of cans which have spoiled, as described above, has shown in all cases the presence of living germs like those of the species originally put into the cans. Thus, for example, cans inoculated with a culture of a large bacillus have been found to contain pure cultures of a large bacillus corresponding in every way to the one originally inoculated into the can.

Sterilization, or "Processing" Experiments.

Our experiments carried on to determine the comparative efficiency of the "dry retort"[1] and the water bath as agencies of sterilization have, without exception, shown the very great superiority of the former. As indicated above, "processing" in the water bath for two and one-half hours does not always produce complete sterilization. On the other hand, there is no reason to doubt the efficiency of the retort if it is properly used. Of over one hundred cans heated in the retort, but otherwise subjected to the same treatment as the water-bathed cans, not one has swelled or shown any evidence of spoiling even under the severe test of standing in the incubator for a month.

In addition to the water-bath experiments above described, a few

[1] The term "retort" is a commercial one, and is open to objection, yet no more so than the term "autoclave," which is used so much in bacteriology, and is applied to the same instrument.

tests have been made to show the effect of continuous boiling for various lengths of time upon the bacteria or their spores. Cans inoculated with these bacteria have been subjected to continuous boiling for periods of four, five, six, seven, and eight hours. In these experiments, mixtures of the bacteria were taken for the inoculating material.

No. of cans.	Time of boiling. (Hours.)	Results.
2	4	Both spoiled in 48 hours.
3	5	2 spoiled in 48 hours. 1 spoiled in 64 hours.
3	6	2 spoiled in 48 hours. 1 spoiled in 64 hours.
3	7	2 spoiled in 48 hours.
4	6	All spoiled.
4	7	All spoiled.
4	8	All spoiled.

These results indicate that the organisms here dealt with have very great resistance to heat — a fact of great interest when taken in connection with the readiness with which spore formation occurs.

For practical as well as for scientific purposes it is obviously important to determine with accuracy minimal periods of retorting required in the various branches of the industry. We have experimented in this direction with highly satisfactory results, and have found it possible to preserve clams and lobsters with ease, and in a more perfect condition, with absolute certainty, with much briefer processing period than is ordinarily used, the only essential being the proper control of the temperature. An account of our numerous experiments in this direction is reserved for a second paper.

Biological Laboratory,
Massachusetts Institute of Technology,
March, 1897.

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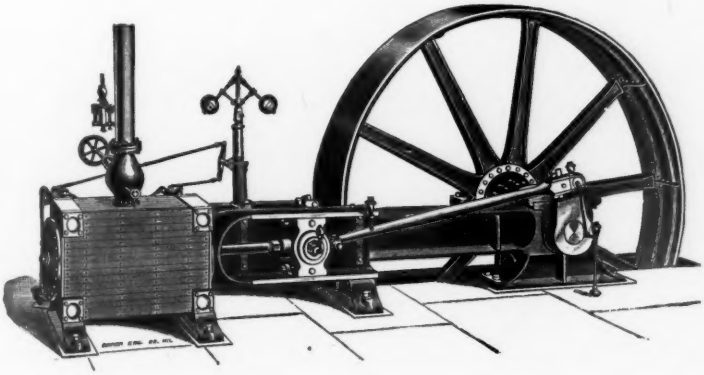

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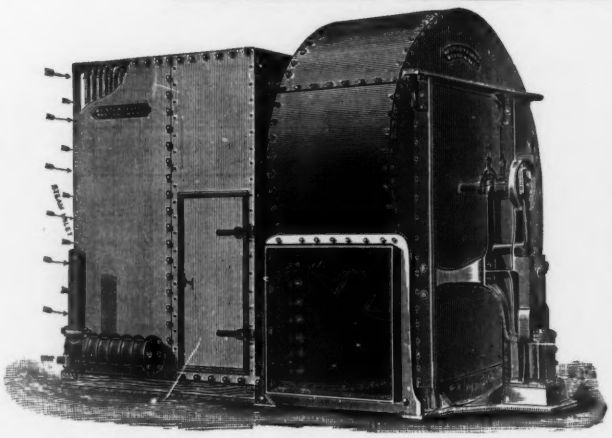

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